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A GUIDE FOR COLLECTING SEISMIC, ACOUSTIC, AND MAGNETIC DATA FOR MULTIPLE USES

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

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Three self-contained documents (Parts 2, 3, and 4) set forth guidelines for the design and implementation of seismic, acoustic, and magnetic signature data collection programs, respectively, such that the data obtained will have general applicability. The information is intended to be a broad reference for planners of such programs. In each part, methods are given for documenting the characteristics of the targets (men, vehicles, etc.) and test sites, instrumentation requirements are set forth, and test procedures are discussed.
(Continued)

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20. ABSTRACT (Continued).

Appendix A explains the generation, propagation, and sensing of microseismic energy.

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PREFACE

This study was conducted from December 1973 to June 1974 under
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COL G. H. Hilt, CE, was Director of WES during conduct of this
study and preparation of the report. Mr. F. R. Brown was Technical
Director.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
Metric (SI) to U. S. Customary		
centimeters	0.3937	inches
meters	3.2808	feet
kilometers	0.6214	miles (U. S. statute)
square centimeters	0.1550	square inches
square meters	10.7638	square feet
kilograms	2.2046	pounds (mass)
newtons	0.2248	pounds (force)
centimeters per second	0.3937	inches per second
U. S. Customary to Metric (SI)		
inches	2.54	centimeters
feet	0.3048	meters
miles (U. S. statute)	1.6093	kilometers
tons (mass)	907.185	kilograms
square inches	6.4516	square centimeters
inches per second	2.54	centimeters per second
volts per inch per second	0.3937	volts per centimeter per second

A GUIDE FOR COLLECTING SEISMIC, ACOUSTIC, AND MAGNETIC DATA FOR MULTIPLE USES

PART 1: INTRODUCTION

Background

1-1. Operational experience and research investigations have proved time and again that the performance of sophisticated materiel items, such as battlefield surveillance devices, is dependent upon the operational environment. It is recognized that significant improvements in battlefield surveillance equipment to make it operable in worldwide environments can come about only by painstaking design.

1-2. State-of-the-art design procedures require large quantities of signature data collected under a wide variety of target and terrain conditions. The usefulness of existing signature data is restricted because the target and terrain conditions under which they were collected are often not adequately documented. Also, new analytical tools or models that show considerable promise in improving existing design techniques require well-documented signature data for their validation. Further, well-documented signature data are needed for extrapolating test results from a specific test condition to conditions expected in a theater of operations.

1-3. The development and use of signature data in the design of surveillance sensors that must perform in worldwide environments are by no means trivial tasks. Signature and ancillary data are often collected (at relatively great expense) for a very restricted purpose. The data may be adequate for the intended purpose; but due to lack of documentation, test control, etc., they have very limited value for other uses. The Project Manager, Remotely Monitored Battlefield Sensor Systems, requested the U. S. Army Engineer Waterways Experiment Station (WES) to develop guidelines for the calculation of signature data for the design of seismic, acoustic, and magnetic sensors. The guidelines outlined several suggestions in test design, target and site

documentation, and instrumentation requirements that are critical to
the design and implementation of signature data acquisition programs of
broad applicability.

Purpose and Scope

1-4.   This report contains, in loose-leaf form, three self-
contained documents (Parts 2, 3, and 4) setting forth general guidelines
for the collection of seismic, acoustic, and magnetic data, respectively.
Illustrations and literature cited in each part are presented therein.
The intended use of signature data dictates the specifications for the
layout and instrumentation for a particular signature acquisition pro-
gram.   The information herein is intended to be a broad reference for
planners of such programs, and not an engineering design manual.   The
following items are discussed in each part:

    <u>a</u>.   Documentation of target characteristics

    <u>b</u>.   Documentation of test site conditions

    <u>c</u>.   Instrumentation for signature recording

    <u>d</u>.   Test procedures

Appendix A explains the generation, propagation, and sensing of micro-
seismic energy.

PART 2: A GUIDE FOR COLLECTING SEISMIC SIGNATURE DATA FOR MULTIPLE USES

Introduction

2-1. The feasibility of using seismic energy to detect, classify, and locate military targets, i.e. men and ground vehicles, has been demonstrated. Many seismic sensors have been designed, developed, and used by the Army; however, improvements and new capabilities are being sought. Seismic sensor development requires analyses of large amounts of seismic signature data, and during the past few years, Department of Defense researchers have collected such amounts for a variety of sensor design purposes. Detailed knowledge of the test conditions under which the data were obtained is often critical to their successful interpretation and analysis. In the majority of instances, the data were adequate for the specialized use for which they were collected, but they were often found to be of limited general value. For example, data generated for the design of detection devices were often inadequate for the design of the more sophisticated classifier and target-position location sensors. Commonly, target characteristics, test site conditions, instrumentation, and test procedures are not sufficiently documented for the recorded signatures to be of general use.

2-2. The seismic signature of a target is the result of a complex interaction of the target, geometry and rigidity of the ground surface over which the target moves, characteristics of the subsurface through which the seismic energy must propagate, and distance from the target. Also, because the energy exploited is normally contained in the Rayleigh (or surface) wave, the ground-surface geometry between the target and sensor can affect the nature of the signal recorded. Appendix A describes in a qualitative way how seismic signals are generated and propagated in terrain materials. This information should be carefully considered (as it applies to a specific test situation) in the design and implementation of seismic signature data collection programs.

Purpose and Scope

2-3. This part of the report is intended to provide guidance for the design and implementation of seismic signature data collection programs such that the data obtained will have general applicability. Methods are given for documenting the characteristics of the targets and test sites, instrumentation requirements are set forth, and test procedures are discussed.

Documentation of Target Characteristics

2-4. The types of targets from which seismic signatures are commonly collected include a walking man, wheeled and tracked ground-contact vehicles, fixed- and rotary-wing aircraft, background noise, and controlled sources. Normally, target vehicles for data collection purposes are selected on the basis of availability, cost, and convenience; therefore, they are usually U. S. Army vehicles. The use of U. S. Army vehicles as substitutes for foreign vehicles should be considered as a temporary or training situation only, since in an armed conflict, vehicles from opposing forces would be of more interest than U. S. vehicles.

2-5. Test-vehicle condition is normally good, but the condition of such components as tires or tracks, mufflers, shock absorbers, etc., can vary from vehicle to vehicle. Researchers should take considerable care in documenting any target idiosyncrasy. The data that should be listed, as a minimum, for the various targets are presented below.

Walking man

    2-6. The following should be listed for walking-man targets:

        a. Name, rank, organization

        b. Weight

        c. Stride length

        d. Shoe type and size

        e. Travel mode, i.e. running, walking, creeping, or crawling

Wheeled ground-contact vehicles

2-7. The following should be listed for wheeled ground-contact vehicles:

a. Nomenclature, including serial and modification numbers

b. Weight (empty)

c. Payload

d. Number of wheels

e. Tire size(s)

f. Number of tire lugs per wheel

g. Tire pressure

h. Tread depth (average)

i. Ground-contact area

j. Number of teeth in the axle gear in the final drive differential

k. Final drive differential gear ratio

l. Engine rpm versus vehicle speed curves for all gears. Vehicle should be loaded and run on level terrain at speeds up to 60 km/hr*

m. Engine model

(1) Horsepower

(2) Number of cylinders

(3) Number of cycles

(4) Fuel type

(5) Cooling type

(6) Location of exhaust

(7) Number of blades in cooling fan

(8) Ratio of fan rpm to engine rpm

2-8. In addition to the characteristics above, the following vehicle parameters should be obtained for producing simulated seismic signatures (using the WES seismic signature simulation models**):

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units and U. S. customary units to metric (SI) is given on page v.

** Procedures and data recording formats have been developed for taking the specified data. For details, contact Director, U. S. Army Engineer Waterways Experiment Station; ATTN: WESFV, Vicksburg, Miss. 39180.

a. Suspension type, i.e. whether the vehicle has:

    (1) Independent suspension

    (2) No suspension, or any combination of independent and no suspension

    (3) Bogie, walking-beam, or any combination of independent, bogie, and walking-beam

    (4) Any combination of (1), (2), and (3)

b. Number of wheels on one side (duals considered as one)

c. Weight (kg) of unsprung mass, i.e. the weight of each wheel assembly. For a solid-axle suspension, use one-half weight of each axle assembly; for no suspension, use zero weight

d. Longitudinal distance(s) (cm) of each wheel center from the center of gravity

e. Static tire deflection at normal (or noted) tire pressure at combat load

f. Pitch inertia ($kg\text{-}sec^2\text{-}cm$) of sprung mass about center of gravity

g. Longitudinal distance(s) (cm) of driver from center of gravity

h. For each suspension unit (wheel assembly), complete suspension spring force-deflection relations from rebound to full bump

Tracked ground-contact vehicles

2-9. The following should be listed for tracked ground-contact vehicles:

a. Nomenclature, including serial and modification numbers

b. Weight (empty)

c. Payload

d. Track pitch

e. Track width

f. Track condition, i.e. actual dimensions of track pads, number and location of broken shoes, etc.

g. Number of track pads on each side in contact with ground

h. Number of teeth on the track sprocket gear

i. Number of teeth in the axle gear in the final drive differential

j. Final drive differential gear ratio

k. Engine rpm versus vehicle speed curves for all gears. Vehicle should be loaded and run on level terrain at speeds up to 60 km/hr

l. Engine model

    (1) Horsepower

    (2) Number of cylinders

    (3) Number of cycles

    (4) Fuel type

    (5) Cooling type

    (6) Number of blades in the cooling fan

    (7) Ratio of fan rpm to engine rpm

2-10. In addition to the characteristics above, the following vehicle parameters should be obtained for producing simulated seismic signatures, as mentioned in paragraph 2-8:

a. Suspension type, i.e. whether the vehicle has:

    (1) Independent suspension

    (2) No suspension, or any combination of independent and no suspension

    (3) Bogie, walking-beam, or any combination of independent, bogie, and walking-beam

    (4) Any combination of (1), (2), and (3)

b. Weight (kg) of unsprung mass, i.e. weight of the road wheel or bogie and one-half weight of the track

c. Longitudinal distance(s) (cm) of each wheel center from the center of gravity

d. Pitch inertia (kg-sec^2-cm) of sprung mass about center of gravity

e. Longitudinal distance(s) (cm) of driver from center of gravity

f. For each suspension unit (wheel assembly), complete suspension spring force-deflection relations from rebound to full bump

g. For each suspension unit with damping, complete force-velocity relations, both in jounce and rebound

h. The length (cm) along the leading portion of the track, measured from beneath the leading road wheel to the foremost part of the track

i. The approach angle (deg) (angle determined by a

horizontal line beneath the leading road wheel and the
leading force of the track)

j. Normal operating track tension (static)

Fixed- and rotary-wing aircraft

2-11. The following should be listed for fixed- and rotary-wing
aircraft:

a. Nomenclature, including serial and modification numbers

b. Weight

c. Payload

d. Number of engines

e. Engine model

(1) Horsepower

(2) Cylinders

(3) Fuel type

(4) Cooling

(5) Number of fan blades

Background noise

2-12. The seismic motion resulting from both ambient and natural
noises and any induced noises created by aircraft (fixed- and rotary-
wing), artillery recoil and shell impacts, animal movement, wind gusts,
rain, etc., should be recorded at each test site at a time when members
of the test team are quiet and motionless. Sampling of the ambient and
induced noises should be accomplished such that the variance in back-
ground noise can be specified on a diurnal basis. The duration and
repetition of the sampling must be tailored to conditions at the site;
however, sampling for 1 min every 30 min for two or three 24-hr periods
will normally yield an adequate representation of background noise.
The source of background noise should be described as precisely as
possible, including (but not limited to) the following:

a. Name of source

b. Continuous or transient

c. Distance from geophone (see paragraphs 2-24 through
2-31 for discussion of geophones)

d. Attitude from geophone

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<u>e</u>. Velocity of the source and direction of motion if
         appropriate

Controlled source

    2-13. The seismic motion resulting from a controlled source is
often useful in comparing the seismic response from one site with that
from another. Normally, a dropped weight[2-1] (electromagnetic or me-
chanical eccentric weight) or a vibrator[2-2] is used as the source.
Sufficient description to define the force-time history of the device-
ground interaction should be included as follows:

Dropped Weight	Vibrator
Type and name	Type and name
Weight of dropped mass	Weight
Drop height	Dimensions of the ground-contact plate
Dimensions of the ground-contact plate	Frequency
Description of the ground-contact plate	Force level
Cushioning, if any	Mode (vertical, torsional, rocking)

Documentation of Test Site Conditions

    2-14. Test site conditions have considerable impact on the nature
of a seismic signal generated by a target (see paragraph 2-2). WES has
developed mathematical relations[2-3] (models) describing the generation
and propagation of signals through terrain materials. Terrain inputs
to these models define the surface and subsurface terrain factors that
must be recorded for quantitative interpretation and extrapolation (to
other terrain conditions) of the recorded signals. These terrain fac-
tors vary in both time and space; therefore, their temporal and spatial
distribution (in relation to target and geophone) must be documented.

    2-15. In general, the test sites should be prepared in a specified
manner for the particular tests to be conducted. The test layout must
be studied on the ground to determine the location of sampling points

for the terrain factors that control the generation and propagation of
the seismic energy. The location of the test course layout and terrain
factor sampling points should be fixed with sufficient accuracy, so that
they can be relocated at any reasonable time in the future. The best
available aerial photographs and topographic maps should be obtained be-
fore a visit to the area of a prospective site. At the site, the sam-
pling point (or test course layout) should be located on the maps and/or
aerial photographs as closely as possible. Then a detailed sketch map
of the immediate vicinity should be made to permit relocation of the
sampling point. The location of the site should be specified by the
geographic coordinate system (degrees, minutes, and seconds of latitude
and longitude) or by the Military Grid Reference System. Details of
both systems can be found in Reference 2-4.

2-16. The terrain inputs to the analytical relations (see para-
graph 2-14) developed at WES define the terrain factors to be measured
at each site (i.e. surface and subsurface factors).[2-1,2-5] Other sup-
plemental data, such as geologic, vegetation, and meteorologic, are also
useful in the interpretation of the generated seismic signatures. Spe-
cific additional requirements are discussed in the following paragraphs.

Surface terrain factors

2-17. The geometry and rigidity of the surface over which the
target travels control the amount of seismic energy generated and cou-
pled to the substrate. For this reason, the surface microgeometry
surveys, cone index readings, and refraction seismic surveys should be
made along the walk lines or vehicle trails. Major surface irregulari-
ties can modify the propagating surface wave; therefore, the ground
surface geometry between the target and geophone must be defined.

2-18. Surface geometry. Surface microgeometry profiles should be
measured with a good-quality surveying level or theodolite. Rod readings
accurate to at least 1 cm should be taken at all major breaks in the walk
line or roadway to define the long-wavelength irregularities. In addi-
tion, several samples (three or four samples 3 m long per 100 m of road-
way) of surface profiles should be obtained with rod readings made every
25 cm. Finally, several samples (three or four samples 50 cm long per

2-8

100 m of roadway) should be obtained with rod readings every 5 cm. The sample points should be selected to characterize the kind and distribution of surface roughness in the roadway.[2-6] The surveys at the three levels of generalization (i.e. rod readings at major breaks in the roadway and at 25 and 5 cm) should be superimposed to reconstruct (statistically) the surface roughness of the trail or roadway. In addition, photographs of the ground surface should always be obtained.

2-19. The surface geometry between the target and geophones should be defined, but the precision can be much less than that required for the trail or roadway.[2-3] In general, sufficient topographic data should be taken to construct contour maps of the area between the target and geophone with a contour interval of 50 cm.

2-20. **Surface soil strength.** Of the several techniques available (e.g. plate load tests, determination of California Bearing Ratio, measurement of cone penetration resistance, etc.[2-7]), the measurement of cone penetration resistance as obtained with the standard soil trafficability cone (Chapters 2 and 9 of Reference 2-7) is the most convenient method for describing surface soil strength for seismic signatures studies. The cone penetrometer is an instrument used to obtain an index of in situ shear strength of soil. It consists of a 30-deg cone with a 0.5- or 0.2-sq-in. base area mounted on one end of a shaft. The shaft has circumferential bands indicating depth of penetration. At the top of the shaft is mounted a dial indicator within a proving ring, which indicates the force applied axially to the penetrometer. The instrument is forced vertically into the soil while records are made of the dial reading for various sinkage depths. For seismic signatures studies, cone index should be measured to a depth of 45 cm. Readings should be taken at 2.5-cm increments to 15 cm. At depths greater than 15 cm, readings should be taken at 7.5-cm increments. At least 15 cone penetration readings should be made (and averaged) for each area where cone penetration resistance measurements are desired.

2-21. The cone penetrometer has been modified by WES so that the cone can be inserted into the ground mechanically. A low-speed reversible electric motor is mounted on a frame that is attached to

the front bumper of a military truck. The motor is used to apply the axial force on the cone. The force is measured by a load cell, and the vertical distance traveled is measured mechanically. Mechanical cone penetrometers should be used, if available. This instrument has three advantages over the standard trafficability cone penetrometer:

a. A more constant force is applied to the cone.

b. Higher cone index values can be obtained with the mechanical cone penetrometer than with the standard trafficability cone penetrometer.

c. The mechanically driven penetrometer can supply an analog signal on both cone index value and depth of penetration, which can be recorded graphically as the test progresses.

2-22. If the walk line or roadway is quite rigid, cone penetration readings cannot be obtained. A description of the walk line or road surface is very important and should include a description of the type and condition of the surface, i.e. concrete, bituminous pavement, brick, stone, crushed rock or coral, waterbound macadam, gravel, natural or stabilized soil, shell, cinders, disintegrated granite, etc.

2-23. Soil moisture and type. Where cone penetrometer readings can be obtained, soil samples for the determination of soil moisture and density should be taken at each cone penetration point at the surface (0- to 5-cm layer) and at depths of 15, 30, and 45 cm. Soil samples obtained at the surface and in each identifiable soil layer found at depths from 5 to 45 cm should be classified according to the Unified Soil Classification System (USCS).[2-8]

2-24. Compression wave velocity. The compression wave velocity and refraction layer thickness of the surface materials over which the target traverses provide a good indication of how the mechanically applied energy will couple to the ground; therefore, these parameters should be measured.* To obtain a measure of the compression wave

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* Shear wave velocity can also be used to estimate how the mechanically applied energy coupled to the ground is applied. Vibratory tests[2-2] can be used to determine shear wave velocity as a function of depth. These data are particularly useful for hard surfaces, such as pavement and gravel roads.

velocity and thickness of the refraction layers, a refraction seismic survey[2-9] must be conducted at each test site. Several portable seismographs are commercially available. WES uses a WES-modified GeoSpace Corporation GT-2B, 12-channel portable seismograph.[2-1] This seismic instrument is designed to record, on film or direct-write oscillograph, shallow refracted data from 1 to 12 inputs, depending on the number of desired recording traces. The X-25 Model L-1 geophones and a double-ended portable spread cable with HS-20 polarized takeouts at 25-ft intervals are used in conjunction with the GT-2B seismograph recorder. The GT-2B recorder has been modified, so that an oscillograph (Century wide-band 444) trace can be seen while testing is in process. Any seismic refraction equipment similar to the above-mentioned items should yield the desired information. To obtain additional definition of the near-surface compression wave velocity and refraction layers, the spacing between geophones should be small (i.e. approximately 25 cm).[2-10] Otherwise, techniques for conducting the survey are similar to more conventional refraction seismic survey techniques (Reference 2-9).

Subsurface factors

2-25. The subsurface factors between the target and geophones that affect the propagating wave are wet density, shear and compression wave velocities, and thicknesses of each refracting layer. Standard refraction seismic surveys (see paragraph 2-24) should be conducted (at selected sampling locations at the test site depending on the diversity of subsurface conditions) such that good definition of the compression wave velocity and layering can be obtained to a depth of 10 m. The selected points should be on a line extending three to five times the desired depth of investigation; thus the length of the line should be 30 to 50 m. Geophone spacing for these lines can be much larger than for the near-surface investigation.

2-26. Soil samples for describing the substrate should be obtained by digging a pit (when possible) to a depth of 1.5 m in the vicinity of several of the refraction survey points and hand-augering a hole approximately 10 cm in diameter from the bottom of the pit to a total depth of 3 m (from the original surface). Soil samples from which moisture

content and wet density can be determined should be obtained at the surface, at 50-cm intervals to a depth of 2 m, and at a depth of 3 m. Bulk samples should also be taken at various depths to determine USCS classification for each identifiable soil layer. These data should be used to interpret the refraction seismic survey at sampling points where soil samples are not obtained.

Supplemental site descriptive data

2-27. Geologic, physiographic, vegetation, and meteorologic data on the site can be quite useful in extrapolating the test results from the site to other areas. Normally, these descriptions will have to be prepared with the aid of personnel (Soil Conservation Service staff, etc.) familiar with the area. The information should include a statement on geology, name of the physiographic and landform unit, site topographic position, depth to the water table, land use, soil parent material, and description of the soil profile.[2-11] Also, vegetation formation, association structure, and species should be identified and listed.[2-12] A formation is a major vegetational unit; for instance, deciduous forest, boreal forest, or grassland. An association is a subdivision of a formation; for example, beech-maple (Fagus-Acer), spruce-fir (Picea-Abies), or short grass (Bouteloua-Bulbilis-Stipa-Agropyron) represent associations of each of the formations listed above. The plant species important in the association in the general areas studied should be listed. This may include trees, shrubs, and herbs (scientific name where possible). The vegetation structure, i.e. the plant height, stem diameter, and spacing, should be noted. The land use, i.e. undisturbed, logged, grazed, cultivated, cultivated (idle), cultivated (grazed), bare, etc., should be listed. Further, wind velocity, temperature, and precipitation (i.e. rainfall and/or snowfall) should be recorded during the test period. Often, it may be desirable (from an economic standpoint) to obtain weather station records in lieu of on-site measurements. The location of the nearest and most representative weather stations should be identified to determine whether their records would be representative of site conditions.

2-28. Instrumentation for recording seismic signals can be either
analog or digital (Figures 2-1 and 2-2). The analog system has a typi-
cal dynamic range of 30-40 db, whereas the digital system has a typical
dynamic range of 50-60 db. The sensing element for both systems is the
geophone. In the analog system, the voltage output of the geophone is
amplified and recorded; in the digital system, the geophone output is
amplified and processed through a low-pass filter and then into a multi-
plex unit. From the multiplex unit, it is converted from an analog to
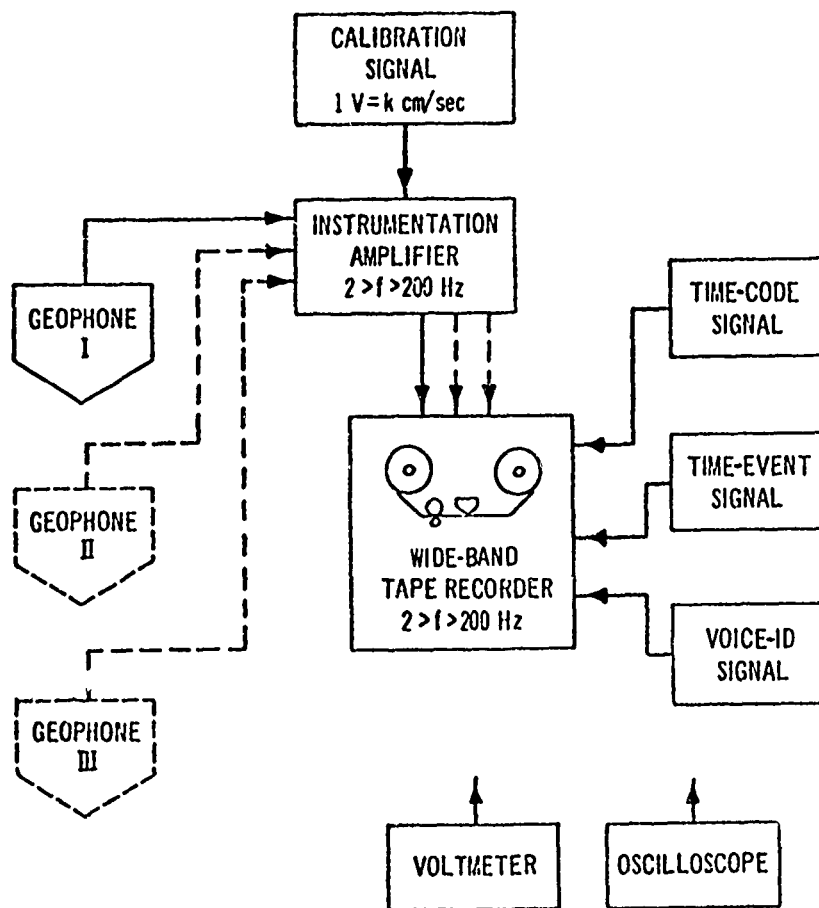a digital record before being recorded. Many possible systems can be

Figure 2-1. Block diagram of the major components
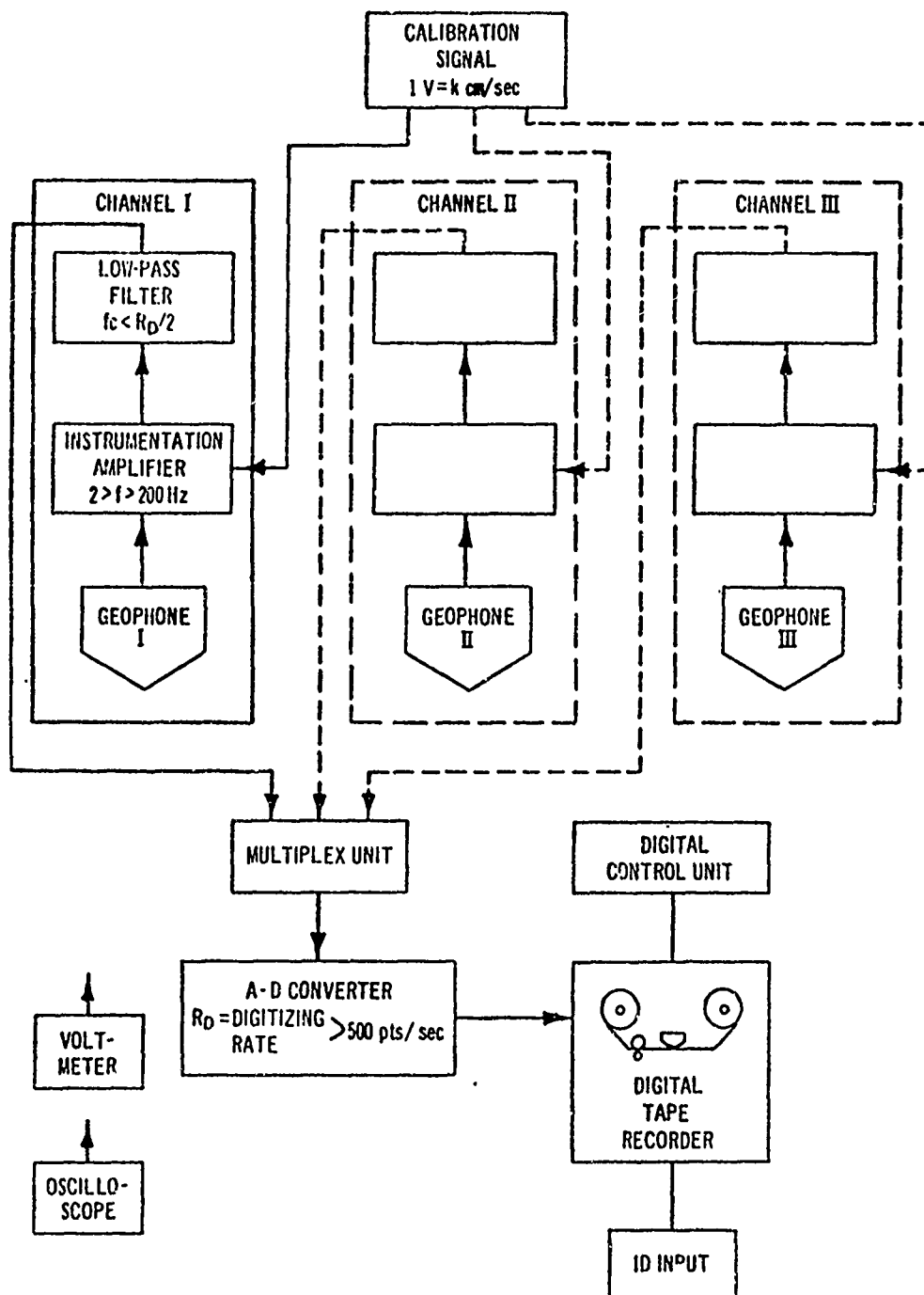in a typical seismic analog recording system

Figure 2-2. Block diagram of the major components in a typical seismic digital recording system

used to measure and record seismic signatures. The following paragraphs discuss several important considerations in selecting the components that make up a system.

Geophones

2-29. Seismic signals propagating in the ground media must be sensed by a transducer that reacts faithfully to each directional and frequency component. A geophone is normally used for this measurement, since a large selection of types is available from many manufacturers. The output from a geophone is a voltage signal (generated by a coil moving in a magnetic field), which is proportional to the particle velocity response of the ground. The electrical specifications for a geophone normally include sensitivity, natural frequency, frequency response, internal impedance, and damping ratio. The sensitivity, given as K volts per cm/sec, describes the output amplitude of the device in response to an input seismic signal. Geophones normally have a linear response over wide input ranges (limited by mechanical stops). The natural frequency of a geophone is the frequency at which the device will oscillate if disturbed from its equilibrium position. The natural frequency marks the practical lower frequency of use for a geophone, since the response decreases sharply for frequencies below the natural frequency. The internal impedance of the geophone is the actual impedance at the output terminals of the device (combination of coil and shunt resistor) and is used to specify the instrumentation amplifier characteristics that will amplify the geophone output. The damping ratio of a geophone is a number that describes the action of an oscillatory system.   ping is the act of reducing the amplitude of the oscillations   ishing the sharpness of resonance of the natural frequency of a system in order to define the relative flatness of frequency response. The damping ratio of a system is the ratio of the degree of the actual damping to the degree of damping required for critical damping.

2-30. The following general guidelines can be given for specifying geophones and their use in the field, which will make the data so collected valuable for many different purposes. In general, triaxial

geophones should be used for general-purpose data collection. The sensitivity of the geophone must be considered when designing the test scenario, e.g., low-sensitivity geophones must be placed closer to a source of seismic waves than high-sensitivity geophones, so the measured signal will be above the background noise and still be within the dynamic range of the geophone. The natural frequency of a geophone should be much lower than the lowest frequency of interest in the seismic wave, e.g., a geophone with a natural frequency of 1 Hz will give good measurements well below 10 Hz. If a damping ratio of a geophone is specified to be between 0.7 and 1.0 of critical damping, good measurements will be obtained with a 1-Hz geophone well below 5 Hz. Selection of geophone natural frequency and damping ratios should be made so that, at a minimum, usable frequencies down to 3-5 Hz are obtained.

2-31. Once the geophone has been selected, care must be used in its emplacement. Mechanical limitations of most geophones require that their cases be placed vertically in the ground, either for single-axis (e.g. vertical) or triaxial geophones. If the geophone case is placed vertically on a sloped topographic feature, the vertical axis of the geophone will not correspond to the normal component of the seismic wave, since the seismic normal component is perpendicular to the ground surface. Thus, where geophones must be placed on nonlevel sites, special nonorientation-sensitive geophones or triaxial geophones should be used to resolve all the seismic wave components. In addition, when the geophone is placed in the ground, it should be isolated as much as possible from acoustic energy, which may couple into the geophone and cause errors in the seismic signal data recording. Generally, much of the acoustic energy from ground-contact vehicles can be eliminated by placing the geophone a few centimeters (at least 5 cm) below the ground surface, carefully packing soil around the geophone case, and covering the geophone top with loose soil. The following are good rules to follow in emplacing the geophone to ensure good ground coupling:

a. Dig a hole approximately the same size and shape as the geophone that is to be buried. The best results will be obtained if the bottom of the hole is flat and the soil disturbance is kept to a minimum.

b. Place the geophone in the hole; be sure that the device base has firm contact with the bottom of the hole.

c. Take care in backfilling the hole. The excavated material should be replaced at as near in situ conditions as possible. As mentioned previously, the seismic signal undergoes reflection and refraction at each interface. This condition causes some of the seismic energy to dissipate (commonly called dispersion). If the soil is backfilled exactly as the soil in situ, the number of interfaces between the source and sensor will be reduced by one. Since this is not altogether possible, the purpose is to approach this homogeneous state, which keeps the properties on each side of the interface similar and the energy decay to a minimum.

Amplifier and calibration circuits

2-32. An instrumentation amplifier is used to amplify the signal from the geophone to a level that can be easily recorded. The amount of gain will depend on both the geophone type (sensitivity), the range from target to detector, and the amount of seismic energy placed in the ground by the target.

2-33. In order that high accuracy can be maintained in the recorded signals, the circuits must be calibrated periodically. The calibration signal is normally introduced to the recording circuit at the amplifier with a simple switching network. The geophone signal is replaced with a precise calibration voltage proportional to the sensitivity of the geophone in use. (Note: Each geophone differs slightly from the manufacturer's nominal sensitivity specifications, so good field technique dictates that each geophone be calibrated to National Bureau of Standards specification on a "shake table" prior to field use.) At the minimum, the instrumentation amplifier should have a frequency response of less than 2 Hz to greater than 200 Hz. Since operational amplifiers that can be used down to zero frequency are readily available, it is advisable to use a frequency ranging from zero to greater than 200 Hz. This reduces the requirements on the calibration signal, also, since it can then be a d-c voltage obtained from a simple voltage divider circuit.

Recording circuits

2-34. As shown in Figures 2-1 and 2-2, there are two basic recording techniques for seismic data, analog and digital. In either method,

several channels of information can be recorded at the same time, simultaneously for the analog technique or sequentially for the digital technique. Both methods require that precision timing networks be utilized, so that accurate spectral information can be recovered from the recorded data up to a frequency of at least 200 Hz. As stated previously, the digital recording technique normally can be expected to have a wider dynamic range than the analog technique, but it requires far more complex equipment.

2-35. As shown in Figure 2-1, the analog signal recording system records each geophone channel on a separate track on the magnetic tape. In addition, a time-code signal (accurate to 1 msec), a time-event signal (a simple keyable voltage), and a voice-identification signal are also recorded on separate tracks. The time-code signal serves as a precise time reference so that even if the tape speed and reproducing systems are not within tolerances, the time between events and the spectral content can still be recovered. The time-event signal serves as a convenient way to record the instant a target position has been referenced (i.e. passed a location stake; see paragraph 2-41). The position of the target and other pertinent test information can be identified on the voice track. If d-c signals are to be recorded, an FM tape recorder is necessary. These multichannel recorders are very rugged and have been used successfully in many field programs. Support equipment for the recording system normally includes voltmeters and oscilloscopes to measure and record pertinent voltage amplitudes and wave forms in the systems or for normal troubleshooting procedures.

2-36. In the digital recording system, the geophone channels are multiplexed so that they can be recorded by a single digital tape recorder. As with any digitizing equipment, a low-pass filter must be used on the signal prior to conversion from analog to digital, so that the high-frequency portion of the total signal is not superimposed on the desired recorded signal. The cutoff frequency of the low-pass filter must be compatible with the digitizing rate, such that the cutoff frequency in Hertz is less than one-half the digitizing rate in points per second. Since no voice channel is available to describe the test while

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in progress, as in the analog technique, test descriptions should be made for the digital technique and associated with an identification (ID) number, which can be formatted on the digital recording.

2-37. Schematics of the equipment used in recording the seismic signatures should be prepared carefully and documented. The field data log should contain the following information with regard to the equipment and signals recorded:

a. Tape width, length, reel size

b. Total number of channels

c. Tape speed (in./sec)

d. Recording mode (frequency modulation, amplitude modulation, etc.)

e. Recording density (per Inter-Range Instrumentation Group (IRIG) standards, i.e. intermediate wide-band I, or wide-band II)

f. Other pertinent information: center frequency, percent deviation, reference IRIG time code, footage readings, revolution counter, voice edge track (A or B), sync reference signal, tape thickness

2-38. WES has developed a small battery-powered (d-c) analog recording system, which has been used successfully in work of this type.[2-1] The battery-powered system eliminates noise that can be caused by the trailer-mounted generators used to power a-c systems. If such a generator is used, care must be exercised to ensure that it is far enough away (at least 300 m) from the geophone and recording equipment to prevent contamination of the recorded signal. This system represents only one of the many possible systems that can be used to record field data successfully in a seismic signature data collection program. The major components and features of the WES analog recording system are given in the following subparagraphs:

a. Seismic signals are measured with Geospace Corporation Model Hs-10-1 scientific geophones, which have a natural frequency of 1 Hz and are able to detect low-frequency seismic information. They are very sensitive, producing 2.95 v/cm/sec while damped 0.7 of critical. Model L4 geophones manufactured by Mark Products, Inc., are also used. The Model L4-1D geophone is a vertical unit mounted in a waterproof housing. It has a 1-Hz

frequency and a sensitivity of 2.36 v/cm/sec and is also damped 0.7 of critical. The triaxial (L4-3D) model contains three geophones mounted in one waterproof housing with a leveling bubble and a directional arrow for one of the horizontal geophones. These geophones have the advantage of quick installation, i.e., in wet environments they do not have to be placed in plastic bags and, for triaxial installation, there is only one piece of hardware to be installed and aligned.

b. An FM magnetic tape recorder, Lockheed Model 417, which records and reproduces seven channels of data at 1-7/8, 3-3/4, and 7-1/2 in./sec, giving frequency responses of DC to 625 Hz, DC to 1250 Hz, and DC to 2500 Hz, respectively, on 1/2-in. tape is normally used. Seismic data are recorded at 1-7/8 in./sec, since the 625-Hz upper limit is adequate for this type of data.

c. A Model 887AB, Fluke Company, digital voltmeter having self-contained batteries is used to monitor the calibration voltages.

d. A Tektronix Model 422 portable oscilloscope is used to monitor the transducer output, the amplifier output to tape recorder, and the tape recorder output.

e. An electronic counter, Systron Donner Model 2014, with its associated power supply is used to align the tape recorder.

f. WES-designed amplifiers using cascaded operational amplifiers produce voltage gains of 0.1 to 1000 and are used to amplify low-amplitude seismic signals.

g. An oscillograph, Century Model 444, is used to make a permanent paper record in the field from the magnetic tape recorder.

2-39. Portions of the previously described equipment are housed in two racks, shock-mounted in fiberglass operating cases made by Environmental Container Systems, which have front and back covers and, when in place, form a shipping container. The other pieces of equipment also have fiberglass transit cases, which protect the units with 2-in.-thick polyurethane. This equipment will operate from four lead-acid automobile batteries for 20 hr before recharging of batteries is necessary. All this equipment can be installed in a small van for field use and transportation. In its present form, this equipment has been shipped by airfreight to various locations throughout the world and has been used successfully in tests conducted thereafter.

2-20

Acoustic measurements

2-40. Normally, acoustic measurements using good-quality broad-band equipment should be made at each test site to complement the seismic data. The guide dealing with acoustic signature data acquisition (Part 3) gives details on how these data are to be collected.

Test Procedures

2-41. The procedures for collecting seismic signature data will vary with test objectives. Normally, a detailed test plan is developed, but it is often modified in actual practice. How the test is actually conducted should be carefully documented. In general, the test should always be designed such that the spatial-time relation between the target (or targets in multiple-target tests) and geophones can be recorded. This requires careful test design; failure to provide a means for reconstructing the position of the target (or targets) as a function of time can be a critical omission in collecting seismic signature data. For example, the test site selected for a walking-man test should, in most cases, consist of a line 110 m long. Stakes at 5-m intervals should be placed along the line so that the man can identify his position by calling out the stake numbers during the test. (The stake numbers are recorded on the voice channel of the seismic response record.) For vehicle targets, a reference line of about 1000 m in length should be laid out with stakes placed at 25- to 30-m intervals. If the test course is over unimproved areas or cross-country, the stake spacing will have to be varied, adapting to curves or profile changes. If the target is airborne (fixed- or rotary-wing aircraft), it is often impractical to attempt to locate it exactly as a function of time. If possible, forward and reverse traverses of the same course should be run to minimize the effects of wind and speed on the acoustically coupled seismic signal. In most instances, the direction, velocity, and altitude can be recorded. Also, it is relatively easy to record whether the aircraft is in level flight, climbing, descending, or changing directions, and such a record should be made.

2-42. In general, it is important to obtain "high-fidelity" data recordings.[2-13] The objective is to bring the test site into the laboratory as nearly as possible. The following items should be considered in test design for signature acquisition for walking-man and vehicle targets:

a. Place geophones, selected on the basis of frequency response and sensitivity, at several locations:

(1) For walking-man tests, 5 to 10 m and 20 to 30 m from closest point of approach. The best choice is somewhat dependent on the attenuation and ambient noise characteristics of the test site.

(2) For vehicle tests, 5 to 10 m, 20 to 30 m, and 50 to 100 m from closest point of approach. The best choice is influenced by site characteristics.

b. Use two or more gain levels for each geophone.

c. Adjust the sensitivity (gain) of one channel to eliminate or minimize recording system saturation at or near the closest point of approach while utilizing high gain on the remaining channel to maximize target range.

d. When selecting geophone gains, be sure to give proper consideration to the very limited dynamic range of the analog tape recorder. At best the range is usually between 30 and 40 db.

(1) A gain of 40 db may be required to eliminate or minimize recording system saturation, but a rather limited useful range will result since the signature amplitude will fall off to the noise level of the recorder at fairly short ranges.

(2) A gain of 100 db may yield maximum target sensitivity, but the recording system may cause saturation from background noise with the target still at a range of several hundred meters.

(3) Gain steps between recorded channels should be from 8 to 20 db; 30-db gain steps are not satisfactory. The data analysis techniques should be used as criteria to determine the optimum gain change between channels.

e. Start and end the planned seismic event beyond the range where the target signature amplitude is equal to or less than the ambient noise amplitude.

f. Monitor the playback of the recording system during actual recording, if possible, to ensure that "good"

data recordings are obtained. It is highly desirable
to detect and correct a problem at the time of actual
recording. Quality of data is far more important than
quantity, and every effort should be made to improve
quality. Too many test sites are committed to use even
when it is found that the site is unsuitable after the
data taking has been initiated.

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PART 3: A GUIDE FOR COLLECTING ACOUSTIC
SIGNATURE DATA FOR MULTIPLE USES

Introduction

3-1. Acoustic energy has been used successfully to detect, classify, and locate military targets throughout history. In earlier times, man used hearing to aid him in determining direction, mode of travel, type of equipment, and number of enemy troops advancing to his position. In modern warfare, the goal is to replace the expert scout with simple and reliable sensors that will yield the same types of information in a more efficient and usable fashion. There have been many advances made in acoustic sensor design and implementation in the past decade, but still new and improved designs and capabilities are needed in acoustic detection methods for battlefield surveillance.

3-2. State-of-the-art design procedures require that acoustic signature data be collected in various ways, depending on the type of sensor to be designed, i.e. classification, target-location, detection, etc. The signature data recorded by various agencies meet their particular criteria, but the results are often useless to other agencies because the test design is too restricted and/or critical parameters are not documented. For example, in tests conducted for the design of detection-only devices, documentation is often made for only a limited number of field parameters in comparison with the rather extensive documentation required for the design of classification and target-location sensors.

3-3. The acoustic signature from a target (walking man, wheeled or tracked ground-contact vehicle, fixed- or rotary-wing aircraft, artillery, background noise, etc.) is the result of complex interactions between the target and the many parameters of the surrounding environment. A complete quantitative understanding of the generation and propagation of the acoustic energy is not available; thus, measured signature data must be used extensively in design. Data collection programs are extremely costly; therefore, complete documentation of the test area and

test procedures is critical if the data are to be usable by researchers having different design goals.

Purpose and Scope

3-4. This document is intended to provide guidance for the design and implementation of acoustic signature data collection programs such that the signature data obtained will have general applicability. Methods are given for documenting the characteristics of the targets and test sites, instrumentation requirements are set forth, and test procedures are discussed.

Documentation of Target Characteristics

3-5. The types of sources (targets from which acoustic signatures are normally collected) include a walking man, wheeled and tracked ground-contact vehicles, fixed- and rotary-wing aircraft, artillery, background noise, and controlled sources. Normally, target vehicles are selected on the basis of availability, cost, and convenience; therefore, they are usually U. S. Army vehicles. The use of U. S. Army vehicles as substitutes for foreign vehicles should be considered as a temporary or training situation only, since in an armed conflict, vehicles from opposing forces would be of more interest than U. S. vehicles.

3-6. Test-vehicle condition is normally good, but the condition of such components as tires or tracks, mufflers, shock absorbers, etc., can vary from vehicle to vehicle. Researchers should exercise considerable care in documenting any target idiosyncrasy. The data that should be listed, as a minimum, for the various targets are presented below.

Walking man

3-7. The following should be listed for a walking-man target:
  a. Name, rank, organization
  b. Weight
  c. Travel mode, i.e. running, walking, creeping, or crawling

d. Talking mode, i.e. silent, softly, normal, above normal

Wheeled ground-contact vehicles

3-8. The following should be listed for wheeled ground-contact vehicles:

a. Nomenclature, including serial and modification numbers

b. Weight (empty)

c. Payload

d. Number of wheels

e. Tire size(s)

f. Number of tire lugs per wheel

g. Tire pressure

h. Tread depth (average)

i. Ground-contact area

j. Number of teeth in the axle gear in the final drive differential

k. Final drive differential gear ratio

l. Engine rpm versus vehicle speed curves for all gears. Vehicle should be loaded and run on level terrain at speeds up to 60 km/hr

m. Engine model

   (1) Horsepower

   (2) Number of cylinders

   (3) Number of cycles

   (4) Fuel type

   (5) Cooling type

   (6) Location of exhaust

   (7) Number of blades in the cooling fan

   (8) Ratio of fan rpm to engine rpm

Tracked ground-contact vehicles

3-9. The following should be listed for tracked ground-contact vehicles:

a. Nomenclature, including serial and modification numbers

b. Weight (empty)

c. Payload

d. Track pitch

3-3

e. Track width

f. Track condition, i.e. actual dimension of track pads, number and location of broken shoes, etc.

g. Number of track pads on each side in contact with ground

h. Number of teeth on the track sprocket gear

i. Number of teeth in the axle gear in the final drive differential

j. Final drive differential gear ratio

k. Engine rpm versus vehicle speed curves for all gears. Vehicle should be loaded and run on level terrain at speeds up to 60 km/hr

l. Engine model

   (1) Horsepower

   (2) Number of cylinders

   (3) Number of cycles

   (4) Fuel type

   (5) Cooling type

   (6) Number of blades in the cooling fan

   (7) Ratio of fan rpm to engine rpm

Fixed- and rotary-wing aircraft

3-10. The following should be listed for fixed- and rotary-wing aircraft:

a. Nomenclature, including serial and modification numbers

b. Weight

c. Payload

d. Number of engines

e. Engine specifications:

   (1) Type, i.e. turbine or piston engine

   (2) Model

   (3) Horsepower

   (4) Number of cylinders

   (5) Fuel type

   (6) Type of cooling

   (7) Exhaust configuration and location

Artillery

3-11. The following should be listed for artillery:

    a. Nomenclature, including serial and modification numbers

    b. Direction of muzzle

    c. Elevation of barrel

    d. Type and load of ammunition

Background noise

3-12. The acoustic propagation resulting from both ambient and natural noises and any induced acoustic noises created by aircraft (fixed- and rotary-wing), artillery firing and shell impacts, animal movement, wind gusts, rain, etc., which are not a part of the desired test sequence, should be recorded at each test site at a time when members of the test team are quiet and motionless. Sampling of the ambient and induced acoustic noises should be accomplished such that the variance in acoustic background noise can be specified on a diurnal basis. The duration and repetitiveness of the sampling must be tailored to conditions at the site; however, sampling for 5 min every 30 min for two or three 24-hr periods will normally yield an adequate representation of acoustic background noise. Whenever possible, data on test site noise should also be collected during the collection of signature data by recording a short quiet period before and after each signature run. The source of acoustic background noise should be described as precisely as possible, including (but not limited to) the following:

    a. Name of source (rain, thunder, cultural activity, etc.)

    b. Continuous or transient

    c. Distance from microphones (see paragraphs 3-26 and 3-27 for discussion of microphones)

    d. Attitude from microphones

    e. Velocity of the source and direction of motion, if appropriate

Controlled source

3-13. Detailed descriptions, including sketches, of the layout of the controlled source generator and microphones should be carefully documented.

Documentation of Test Site Conditions

3-14. Test site conditions have considerable impact on the nature of the acoustic signal from a target. In general, the test sites should be prepared in a specified manner for the particular tests to be conducted. The test layout must be studied on the ground to determine the location of sampling points for the terrain factors that control the generation and propagation of the acoustic energy. The location of the test course layout and terrain factor sampling points should be determined with accuracy sufficient to permit relocation at any reasonable time in the future. The best available aerial photographs and topographic maps should be obtained before a visit to ~ prospective site. At the site, the sampling point (or test course layout) should be located on the map and/or aerial photographs as closely as possible. Then a detailed sketch map of the immediate vicinity should be made to permit relocation of the sampling point. The location of the site should be specified by the geographic coordinate system (degrees, minutes, and seconds of latitude and longitude) or by the Military Grid Reference System. Details of both systems can be found in Reference 3-1.

3-15. Surface terrain factors, soil moisture and type, vegetation, and other data, such as geologic, physiographic, and meteorologic, are needed in the interpretation of the generated acoustic signatures. Wide-angle line-of-sight photographs taken from the microphone location to the source provide valuable information on the transmission path. Specific additional requirements are discussed in the following paragraphs.

Surface terrain factors

3-16. The geometry and rigidity of the surface over which the target travels partially control the amount of acoustic energy generated into the atmosphere. For this reason, surface microgeometry surveys and cone index readings should be made along the walk lines or vehicle trails (see paragraph 3-39). Major surface irregularities can modify the acoustic energy propagating from the target; therefore, these irregularities should be documented.

3-6

3-17. __Surface geometry__. Surface microgeometry profiles should be measured with a good-quality surveying level or theodolite. Rod readings accurate to at least 1 cm should be made at all major breaks in the walk line or vehicle trail to define the irregularities. In addition, photographs of the ground surface should always be obtained. The surface geometry between the target and acoustic sensor should be defined. In general, sufficient topographic data should be taken to construct contour maps of the area between the target and acoustic sensor with a contour interval of 50 cm.

3-18. __Surface soil strength__. The amount of power (which is related to engine noise) required to propel a vehicle is directly related to soil strength. The cone penetrometer is an instrument used to obtain an index of in situ shear strength of soil.[3-2] It consists of a 30-deg cone with a 0.5- or 0.2-sq-in. base area mounted on one end of a shaft. The shaft has circumferential bands indicating depth of penetration. At the top of the shaft is mounted a dial within a proving ring, which indicates the force applied axially to the penetrometer. The instrument is forced vertically into the soil while records are made of the dial reading for various sinkage depths. For acoustic signature studies, cone index should be measured to a depth of 30 cm. Readings should be taken at 2.5-cm increments to 15 cm. At depths greater than 15 cm, readings should be taken at 7.5-cm increments. At least five cone penetration readings should be made (and averaged) for each area where soil strength measurements are desired.

3-19. The cone penetrometer has been modified by WES so that the cone can be inserted into the ground mechanically. A low-speed reversible electric motor is mounted on a frame that is attached to the front bumper of a military truck. The motor is used to apply the axial force on the cone. The force is measured by a load cell, and the vertical distance traveled is measured mechanically. Mechanical cone penetrometers should be used, if available. This instrument has three advantages over the standard cone penetrometer:

     __a__. A more constant force is applied to the cone.

     __b__. Higher cone index values can be obtained with the

mechanical cone penetrometer than with the standard trafficability cone penetrometer.

c. The mechanically driven penetrometer can supply an analog signal of both cone index value and depth of penetration, which can be recorded graphically as the test progresses.

3-20. If the walk line or roadway is quite firm, cone penetration readings cannot be obtained. A description of the walk line or road surface is very important and should include a description of the type and condition of the surface, i.e. concrete, bituminous pavement, brick, stone, crushed rock or coral, waterbound macadam, gravel, natural or stabilized soil, shell, cinders, disintegrated granite, etc.

Soil moisture and soil type

3-21. Soil moisture and soil type have a measurable effect on acoustic reflection or absorption. Where cone penetrometer readings can be obtained, soil samples for the determination of soil moisture and density should be taken at each cone penetration point from the surface (0- to 5-cm layer) and at depths of 15, 30, and 45 cm. Also, the samples should be classified according to the Unified Soil Classification System.[3-3]

Vegetation

3-22. The vegetation structure, i.e. plant height, stem diameter, stem spacing, and leaf presence and density, should be measured in accordance with the procedures specified in Reference 3-4. Vegetation formation, association structure, and species should be identified and listed. A formation is a major vegetational unit; for example, deciduous forest, boreal forest, or grassland. An association is a subdivision of a formation; for example, beech-maple (Fagus-Acer), spruce-fir (Picea-Abies), and short grass (Bouteloua-Bulbilis-Stipa-Agropyron) represent associations of each of the formations listed above. The important plant species in the general area studied should be listed.[3-4] These may include trees, shrubs, and herbs (scientific name where possible).

Supplemental site descriptive data

3-23. Geologic, physiographic, and meteorologic data on the site

can be quite useful in interpreting and extrapolating the test results from the site to other areas. Normally, these descriptions will have to be prepared with the aid of personnel (Soil Conservation Service staff, etc.) familiar with the area. The information should include a statement on geology, name of the physiographic and landform unit, site topographic position, depth to the water table, land use, soil parent material, and description of the soil profile.[3-5] The land use, i.e. undisturbed, logged, grazed, cultivated (idle), cultivated (grazed), bare, etc., should be listed. Further, wind velocity and direction, temperature, and precipitation (i.e. rainfall and/or snowfall) should be recorded during the test period. Often, it may be desirable to obtain weather station records to augment the on-site measurements. The location of the nearest and most representative weather stations should be identified to determine whether their records would be representative of on-site conditions.

3-24. In determining adequacy of records, the interaction of the acoustic energy and site conditions should be considered. For example, wind blowing at even very low (3-5 mph) velocities causes leaves to rustle, and thus the noise of wind in trees affects background noise level. Humidity has a measurable effect on sound absorption. Noise is propagated more efficiently downwind than upwind. The effects of temperature are particularly evident under changing weather conditions, such as certain crisp cold conditions that result in temperature "inversions." Also, a blanket of snow reduces the audibility range because it absorbs acoustic energy.

Instrumentation for Recording Acoustic Signals

Acoustic signal recording

3-25. As shown in Figure 3-1, the instrumentation for an acoustic recording system consists of a microphone, a preamplifier, a frequency-sensitive electrical network (generally a filter or smoothing circuit), an amplifier, and a recorder. The microphone, the sensing element, is exposed to the environment. Care must be taken to ensure that spurious
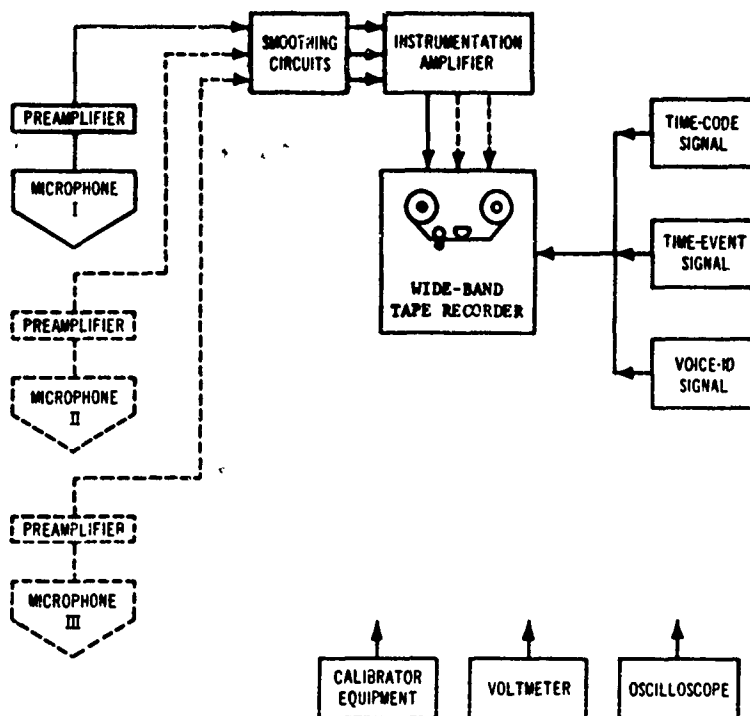
Figure 3-1. Block diagram of the major components
in a typical acoustic analog recording system

signals do not obscure target signals. All instrumentation equipment
used to measure and record acoustic signatures should be of high quality;
the results of any test program can be only as good as the data recorded.
The following paragraphs discuss several important considerations in
selecting the components that make up a system.

3-26. Microphones. Acoustic signals propagating in the atmosphere
must be sensed by a transducer that reacts faithfully to each loudness
and frequency component. Such a transducer is a microphone. It changes
the pressure variations of an acoustic wave into electrical signals pro-
portional to the pressure variations. Microphones used to record target
signatures usually fall into one of three types: crystal, ceramic,
or condenser. Crystal microphones are usually not used because of
their poor frequency response; however, they do have high sensitivity
and, therefore, can be used as special transducers when power and cost
requirements are critical. The ceramic microphones are noted for their

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ruggedness and their insensitivity to humidity and temperature changes. They are well-suited to the bulk of acoustic measurements made. The condenser microphones feature somewhat smoother frequency responses.

3-27. Specifications for a microphone usually include frequency response, sensitivity, and impedance. Microphones normally have a linear response over a wide range of pressure levels, though at extremely high-pressure levels, the distortion of the measured sound increases appreciably. The frequency response of a microphone selected for field recordings should be as uniform as possible over the range of interest; for multipurpose data, the frequency response should be 20 to 20,000 Hz (up to 40,000 Hz if ultrasonic signals are of interest). Sensitivities should typically be on the order of -60 db (referred to 1.0 v per microbar).

3-28. Preamplifier, smoothing circuit, and amplifier. A preamplifier is used between the microphone and the measuring or recording instruments for two reasons: to amplify the signal and to match the microphone to connecting cables. A preamplifier makes possible the use of cables up to several thousand feet in length without significant signal degradation. If the preamplifier is physically located at the microphone position, it immediately raises the signal level of the microphone output, so that if noise enters the system at points between the amplifier and recorder, its effect on the recorded signal is reduced.

3-29. Smoothing circuits or filters are used to select portions of the total spectrum for processing, to reduce noise on a desired signal, or to make the response of a frequency-sensitive element more uniform. These smoothing circuits can often improve the quality of recorded signals, but it must be recognized that data modified in this manner are irrecoverable unless the exact reciprocal of the filter network used in recording is used to reshape the data when they are reproduced. For this reason, the use of smoothing circuits must be carefully documented if signals are measured for multipurpose use.

3-30. The amplifiers must be capable of amplifying all frequencies contained in the measured signals. Typically, this would be from 20 to 20,000 Hz, or if ultrasonic signals are desired, to 40,000 Hz. If one

amplifier cannot cover the entire bandwidth of 20-40,000 Hz, a second amplifier can be used for the 20,000- to 40,000-Hz band. Also, it is often desirable to measure and amplify acoustic phenomena for frequencies less than 20 Hz. Microphones that have frequency response down to 1 or 2 Hz are available for this purpose.

3-31. Recording circuits. The analog signal recording system (see Figure 3-1) records each microphone channel on a separate track on magnetic tape. In addition, a time-code signal (accurate to 1 msec), a time-event signal (a simple keyable voltage), and a voice-identification signal are also recorded on separate tracks. The time-code signal serves as a precise time reference, so that even if the tape speed and reproducing systems are not within tolerances the time between events and the spectral content can still be recovered. The time-event signal serves as a convenient way to record the instant a target position has been referenced (i.e. passed a location stake; see paragraph 2-39). The position of the target and other pertinent test information can be identified on the voice track. If d-c signals are to be recorded, an FM tape recorder is necessary. Support equipment for the recording system normally includes voltmeters and oscilloscopes to measure pertinent voltage amplitudes and wave forms in the system or for normal troubleshooting procedures.

3-32. Schematics of the equipment used in recording the acoustic signatures should be prepared carefully. The field data log should contain the following information with regard to the equipment and the signals recorded:

<u>a</u>. Tape width, length, reel size

<u>b</u>. Total number of channels

<u>c</u>. Tape speed (in./sec)

<u>d</u>. Recording mode (frequency modulation, amplitude modulation, etc.)

<u>e</u>. Recording density (per Inter-Range Instrumentation Group (IRIG) standards, i.e. intermediate, wide-band I, or wide-band II)

<u>f</u>. Sound-level meter-weighing networks (i.e. A, B, C, D) used in the gathering of data must be correctly

documented according to American National Standards Institute (ANSI) or International Standardization Organization (ISO) standards. Instruments in the United States are manufactured to ANSI standards, but foreign-made equipment generally conforms to standards of the ISO. The two standards are not identical, although they are very much alike and should not be confused

g. Other pertinent information: center frequency, percent deviation, reference IRIG time code, footage readings, revolution counter, voice edge track (A or B), sync reference signal, tape thickness

Calibration

3-33. The first step in using any sound-measuring equipment is calibration. Calibration ensures that the instruments are functioning properly and reading correctly. Calibration should be accomplished by feeding very accurate acoustic signals into the microphones at a number of preselected frequencies using a reference signal generator (piston-phone) and a high-precision acoustic transducer. Measured variations in signal level from test to test can then be used as a correlation factor in the recorded acoustic signals. Calibration signals should be measured at the beginning and end of each recording sequence (i.e., each time the recorder is turned on, and prior to the time it is turned off).

Specifications for representative equipment

3-34. Systems made up of components of equal or superior quality should provide high-quality recordings for most general-purpose signature acquisition requirements. The following specifications for instrumentation equipment are for general information:

a. Microphones

(1) Bruel and Kjaer (B&K) Type 4133; sensitivity 12.5 v/N/m^2; frequency response 5-40,000 Hz; dynamic range 150 db

(2) General Radio (GR) Type 1560-PS, P6; sensitivity 40-60 db re 1 v/μb; frequency response 5-20,000 Hz; dynamic range 22-145 db

(3) General Radio (GR) Type 1963-9602; sensitivity 58 db re 1 v/μb; frequency response 20-35,000 Hz; dynamic range 49-150 db

b. Preamplifier. The General Radio (GR) 1560-P42 is a high-input, low-noise preamplifier

<u>c</u>. <u>Recording units</u>

    (1) The FM analog tape recorder should have sufficient dynamic range, frequency response, and signal-to-noise ratio plus isolation between adjacent channels

    (2) The sound-level meter can be one of two types:

        (a) Type 2203 Bruel and Kjaer; range 22-134 db; frequency response 10-20,000 Hz flat

        (b) Type 1551-C General Radio; range 24-150 db; frequency response 20-20,000 Hz

    (3) Windscreens should reduce noise 20 db in winds of 30 mph; Bruel and Kjaer, and General Radio

    (4) The octave-band analyzer can be one of two types:

        (a) Bruel and Kjaer Type 2203 with 4131 microphone and 1613 filter set

        (b) General Radio Type 1558; range 44-150 db; frequency response 3-30,000 Hz flat; filter networks, center frequency 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz; output 1 v RMS (nominal)

<u>d</u>. <u>Calibration</u>

    (1) Bruel and Kjaer Type 4220 pistonphone; sound-pressure level 124 db $\pm$ 2 db; output frequency 250 Hz; distortion 30 percent or less

    (2) General Radio Type 1562A; sound-pressure level 114 db $\pm$ 0.3 db; output frequency 125, 250, 500, 1000, and 2000 Hz $\pm$ 3 percent; distortion 0.5 percent or less

<u>Controlled source</u>

3-35. The acoustic signal propagation resulting from a controlled source is often useful in comparing the acoustic response from one site with another. The controlled source should have the capability of producing a broad spectrum of frequencies for specialized tests. Specifications for instrumentation are given in paragraph 3-37.

3-36. The data collected using a controlled-source system may be analyzed with site documentation data to explain site-induced anomalies in the acoustic signature data. For example, the presence of vegetation at a site causes anomalies to occur in the acoustic signature because of reflections and refractions resulting from the acoustic wave impinging

on the leaves, branches, and stems of the vegetation. The frequency-
dependent attenuation could be determined as a function of the density,
height, and type of vegetation, and this information could be considered
in the design of the acoustic sensor.

3-37. A simplified block diagram for generating, receiving, and
recording controlled source information is given in Figure 3-2. The
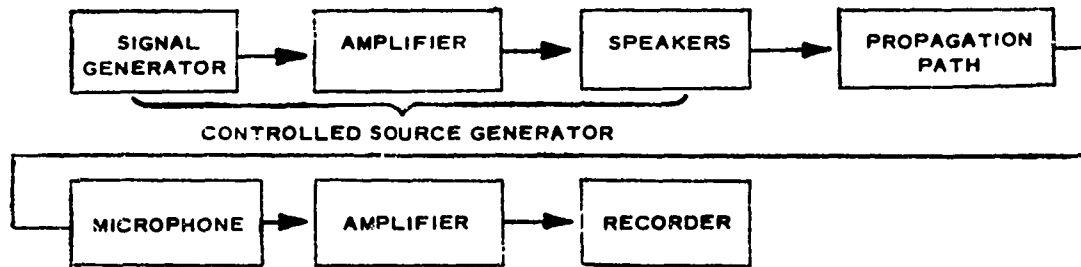

Figure 3-2. Block diagram of controlled source system

following equipment will provide adequate instrumentation for most con-
trolled tests:

a. Signal generator. General Radio Model 1396-B tone-burst,
   DC to 2 MHz; signal attenuated 60 db between bursts;
   burst length 10 µsec to 10 sec or controllable by
   separate input. Frequency synthesizer is a highly
   accurate tunable oscillator; Model 1310-B, 2 Hz to 2 MHz.

b. Amplifier for signal generator. General Radio Model
   1308-A power amplifier 20-20,000 Hz, 200 VA output;
   output transformer; high-frequency power amplifier.

c. Speakers. There are many sources of high-quality
   speakers available. The power rating and frequency
   range should exceed the test parameters.

Supporting instrumentation

3-38. In WES acoustic data collection programs, the following
supporting instrumentation has been found useful:

a. A Fluke Company Model 887AB digital voltmeter having
   self-contained batteries is used to monitor the calibra-
   tion voltages.

b. A Tektronix high-frequency (0-50,000 Hz) portable oscil-
   loscope is used to monitor the microphone output, the
   amplifier output to tape recorder, and the tape recorder
   output.

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<u>c</u>. An electronic counter, Systron Donner Model 2014, with
its associated power supply is used to align the tape
recorder.

<u>d</u>. WES-designed amplifiers using cascaded operational ampli-
fiers produce voltage gains of 0.1-1000 and are used to
amplify low-amplitude signals.

<u>e</u>. An oscillograph, Century Model 444, is used to make a
permanent paper record in the field from the magnetic
tape recorder.

Test Procedures

3-39. Test procedures will vary with test objectives. Normally,
a detailed test plan is developed, but it is often modified in actual
practice. How a test is actually conducted should be carefully docu-
mented. In general, the test should always be designed such that the
spatial-time relation between the target (or targets in multiple-target
tests) and acoustic sensors can be recorded. This requires careful test
design; failure to provide a means for reconstructing the position of
the target (or targets) as a function of time can be a critical omission
in collecting acoustic signature data. For example, the test site se-
lected for a walking-man test should, in most cases, consist of a line
110 m long. Stakes at 5-m intervals should be placed along the line, so
that the man can identify his position at each stake during the test.
(The stake numbers are recorded on the voice channel of the acoustic re-
sponse record.) For vehicle targets, a reference line of about 1500 m
in length should be laid out with stakes placed at 25- to 30-m intervals.
If the test course is over unimproved areas or cross-country, the stake
spacing will have to be varied, adapting to curves or profile changes.
If the target is airborne (fixed- or rotary-wing aircraft), it is
often impractical to attempt to locate it exactly as a function of
time. If possible, forward and reverse traverses of the same course
should be run to minimize the effects of wind on the acoustic signals.
In most instances, the direction, velocity, and altitude can be recorded.
Also, it is relatively easy to record whether the aircraft is in
level flight, climbing, descending, or changing directions and/or

power settings, and such a record should be made.

3-40.   In designing the sensor arrays for field tests, considera-
tion should be given to the target and target-operational modes. Each
target presents different acoustic characteristics in terms of loudness
and frequency as a function of operational mode. A vehicle idling at
constant rpm or in motion at constant low speed will produce less sound
than one operating at higher speed or changing speed. In general, the
vehicle operating mode should be varied as much as practicable. Slow-
moving vehicles traveling at constant speeds are generally the most
difficult vehicle-operational modes to detect and, therefore, should be
given high priority in any signature acquisition program. It is empha-
sized that vehicle testing should be conducted using a variety of
vehicle speeds and accelerations.

3-41.   In general, the most significant factor in the attenuation
of sound (with increase in distance) in a free field is that attributed
to the inverse square law of spherical divergence. This loss or reduc-
tion is called "decibels per distance double" (abbreviated db/dd).[3-6]
The loss of sound in db/dd can be explained as follows: If a sound has
a level of 30 db at a distance of 100 ft and a level of 24 db at double
the distance, 200 ft, then the loss per distance double is 6 db, or
6 db/dd.

3-42.   For field conditions where there are no echoes or reflec-
tions from buildings, hills, or other obstructions, sound decreases for
short distances at about 6 db/dd. This loss is, however, affected by
atmospheric and terrain conditions and varies with frequency. The
distance double figure can be used to approximate sound levels of vehi-
cle noise at distances up to about 1 mile, based on measurements close
to the source.

3-43.   The sensitivity of the microphone must be considered in
designing the test scenario, e.g., low-sensitivity microphones should be
placed closer to a source of acoustic waves, so that the measured signal
will be above the background noise and still be within the dynamic range
of the microphone. If the background noise is very great, the micro-
phone can be moved closer to the source to increase the source-signal

level (i.e. reduce the attenuation of the signal caused by range). In general, the distance between the microphone and the test item should not be reduced to where the test item can no longer be considered a point source (i.e. approximately twice the length of the longest wavelength of interest). Also, the signal-to-background noise requirements should be established prior to the test program. Of course, the prerequisites depend on the intended data application.

3-44. The placement of the microphone must be considered if high-quality signals are to be recorded. Normally, the microphone should be placed in a fashion to eliminate noise from wind. This noise can be either a rattle or a vibration from the microphone stand or from nearby vegetation structures. A good-quality windscreen should be used on the microphone to reduce the noise of the wind generated around the microphone structure itself without attenuating the high-frequency components appreciably. It is emphasized that the attenuation specifications of any windscreen used should be documented.

3-45. The microphone and stand should be located away from reflecting surfaces, such as lines of dense vegetation, large topographic features, man-made structures, etc. The location of the microphone should be documented very carefully in all cases since position is very important in the interpretation of the signals. For example, the attenuation rate for a site located on a smooth body of water is much different from that for a site inside a dense stand of vegetation. The height of the microphone above the ground should be the design height of the acoustic sensor for which the data are being collected. A more general test design would involve several microphones mounted at different heights. For example, data for sensors designed for deployment in trees should be collected at relatively high measurement points, data collected for training Army personnel should be taken at ear level, etc. Data collected at several locations during a single test would provide information on signal degradation (resulting from reflections, etc.) as a function of microphone location. This information will be useful to the designer in the selection of signal processing techniques to be used in tactical sensors, which are relatively insensitive to signal

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degradation resulting from microphone positioning.

3-46. To obtain data for the design of target-position location devices, omnidirectional microphone arrays (i.e. the microphones placed at the vertices of an equilateral triangle) should be used in lieu of single microphones. The microphone spacing in the array will depend on the frequencies of interest; it should be less than half the shortest wavelength of interest to avoid ambiguity in the measured time displacement between the signatures received at each of the microphones.

3-47. Directional data can also be collected with special acoustic sensors made up of three microphones, i.e. two microphones with directional characteristics and one omnidirectional microphone. It should be recognized that collecting signature data useful for designing target-position location devices requires additional instrumentation considerations. Use of the omnidirectional microphone arrays requires that the phase relation of the signals from the omnidirectional microphones be accurately maintained during the entire recording-reproducing procedure. Use of the three microphones requires that the relative amplitude responses of the three microphones be maintained.

3-48. In general, it is important to obtain "high-fidelity" data recordings.[3-7] The objective is to bring the test site into the laboratory as nearly as possible. The following items should be considered in the design of tests for signature acquisition from walking-man and vehicle targets:

  a. Place acoustic sensors, selected on the basis of frequency response and sensitivity, at several locations.

    (1) For walking-man tests, 5-10 m and 20-30 m from closest point of approach. The best choice depends somewhat on the attenuation and ambient acoustic noise characteristics of the test site.

    (2) For vehicle tests, 25-100 m, 50-200 m, and 300-600 m from closest point of approach. The best choice is influenced by site characteristics.

  b. Attempt to obtain data with wide dynamic range. One (of several) simple method is to use two or more gain levels for each microphone.

  c. Adjust sensitivity (gain) of one channel to eliminate or minimize recording system saturation at or near the

closest point of approach while using high gain on the remaining channel to maximize target range.

d. When selecting microphone gains, be sure to give proper consideration to the very limited dynamic range of the analog tape recorder. At best the range is usually between 30 and 40 db.

(1) A gain of 40 db may be required to eliminate or minimize recording system saturation, but a rather limited useful range will result, since the signature amplitude will fall off to the noise level of the recorder at fairly short ranges.

(2) A gain of 100 db may yield maximum target sensitivity, but the recording system may be saturated by background noise with the target still at a range of several hundred meters.

(3) Gain steps between recorded channels should be from 8 to 20 db. The data analysis techniques should be used as criteria to determine the optimum gain steps between channels.

e. An important part of any data collection program is the calibration of all components of the system. Widely accepted calibration procedures are given in References 3-8 through 3-11. The calibration equipment should have performance specifications that exceed those of the complete recording system, and all equipment (including the sensor and recording system) should be documented as to manufacturer, type, modifications, and operating conditions. A fixed calibration signal of a known intensity should be coupled to the microphone prior to performing each test to allow direct intensity measurements for each test by comparing sound levels. In lieu of a fixed calibration signal, it may be desirable to use a controlled impulse signal (see paragraphs 3-35 through 3-37). A comparison of the Fourier transforms of the impulse and output signals will provide a description of the response characteristics of the recording over a relatively broad bandwidth.

f. If possible, start and end the planned acoustic event beyond the range where the target signature amplitude is less than the acoustic ambient noise amplitude. Often, military vehicle acoustic signatures are detectable above the background noise at distances in excess of 3 miles. In some instances, therefore, it will be necessary to start the test closer than the range where the target signature amplitude is less than the ambient noise. In these cases, the maximum range practicable should be used.

g. Monitor the measured signals during actual recording, if possible, to ensure that "good" data recordings are obtained. It is highly desirable to detect and correct any problems at the time of actual recording. Quality of data is far more important than quantity, and every effort should be made to improve quality. Too many test sites are committed to use even though they are found unsuitable after the data taking has been initiated.

3-49. As stated in the guide dealing with the collection of seismic data (Part 2), acoustic and seismic data should normally be collected concurrently. As a minimum, the seismic response should be measured at each microphone location with a vertical geophone.

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PART 4: A GUIDE FOR COLLECTING MAGNETIC
SIGNATURE DATA FOR MULTIPLE USES

Introduction

4-1. Throughout history many methods have been used to detect,
classify, and locate military targets. Since many of these targets are
at least partially composed of ferromagnetic materials (vehicles, sub-
marines, mines, aircraft, etc.), the measurement of magnetic fields
around these targets has proven effective for target detection in many
military operations. With the aid of fixed and/or moving magnetometers,
the methods and equipment for the locations of submarines and metallic
mines have, in the past, been a major area of military technology.

4-2. As is generally known, the earth acts like a large bar mag-
net, with the negative magnetic pole in the north and the positive mag-
netic pole in the south. A directional compass becomes oriented along
the line called the magnetic meridian, which deviates from a direct arc
between the magnetic poles as a result of so-called magnetic anomalies
created by local irregularities in the earth's field. As with a common
bar magnet, the earth's magnetic field can be represented by a series
of lines of force between the magnetic poles. Because most of the mag-
netic field appears to emanate from within the earth, the magnetic lines
of force are vertical at the magnetic poles and horizontal midway be-
tween the poles (i.e. along the magnetic equator). Between the magnetic
poles and the magnetic equator the earth's field has both a vertical and
a horizontal component.

4-3. When a ferromagnetic object is placed within a uniform mag-
netic field, the field in the vicinity of the object will be disturbed.
..en though the earth's magnetic field may not be uniform, a magnetic
moment will be induced if a ferromagnetic object is placed on it. The
magnetic field of this induced dipole distorts the otherwise uniform
geomagnetic field, and a magnetometer carried through the vicinity of
the dipole shows an anomalous fluctuation in its output signal. This
fluctuation is known as the magnetic signature of the object.[4-1]

4-4. The magnetic signature of a target (fully equipped combat
soldier, wheeled and tracked ground vehicles, background noise, etc.)
is the result of complex interactions among the target and the many
parameters of the surrounding environment. Although many theoretical
and experimental studies have been conducted with emphasis directed
toward target orientation, direction and velocity of travel, physical
size, and range to target, there still exists a need for quanti-
tative understanding of the way a magnetic signature is established.
Data collection programs are extremely costly; therefore, complete
documentation of the test area and test procedures is critical if the
data are to be usable by researchers with different design goals.

Purpose and Scope

4-5. This document is intended to provide guidance for the design
and implementation of magnetic signature data collection programs such
that the signature data generated will have general applicability.
Methods are given for documenting the characteristics of the targets
and test sites, instrumentation requirements are set forth, and test
procedures are discussed.

Documentation of Target Characteristics

4-6. The types of energy sources (magnetic dipole moments of
targets) from which magnetic signatures are collected include a fully
equipped combat soldier, wheeled and tracked ground vehicles, background
noise, etc. Normally, target vehicles are selected on the basis of
availability, cost, and convenience; therefore, they are usually U. S.
Army vehicles. The use of U. S. Army vehicles as substitutes for
foreign vehicles should be considered as a temporary or training situa-
tion only, since in an armed conflict, vehicles from opposing forces
would be of more interest than U. S. vehicles.

4-7. Test-vehicle condition is normally good, but the condition

of such components as tires or tracks, mufflers, shock absorbers, etc., can vary from vehicle to vehicle. Researchers should exercise considerable care in documenting any target idiosyncrasy. The data that should be listed, as a minimum, for the various targets are presented below:

Walking man

4-8. The following should be listed for a walking-man target:

    <u>a</u>. Name, rank, organization

    <u>b</u>. Travel mode, i.e. running, walking, creeping, or crawling

    <u>c</u>. Personal components, i.e. helmet, rifle (including orientation), etc.

    <u>d</u>. Velocity in m/sec

Wheeled ground-contact vehicles

4-9. The following should be listed for wheeled ground-contact vehicles:

    <u>a</u>. Nomenclature, including serial and modification numbers

    <u>b</u>. Weight (empty)

    <u>c</u>. Payload (weight and description)

    <u>d</u>. Velocity in m/sec

    <u>e</u>. Number of wheels

    <u>f</u>. Tires (size and tire pressure)

    <u>g</u>. Engine model:

        (1) Number of cylinders

        (2) Horsepower

        (3) Fuel type

        (4) Type of cooling

Tracked ground-contact vehicles

4-10. The following should be listed for tracked ground-contact vehicles:

    <u>a</u>. Nomenclature, including serial and modification numbers

    <u>b</u>. Weight (empty)

    <u>c</u>. Payload (weight and description)

    <u>d</u>. Track pitch

    <u>e</u>. Track width

  <u>f</u>. Track condition, i.e. actual dimensions of track pads, number and location of broken shoes, etc.

  <u>g</u>. Number of track pads on each side in contact with the ground

  <u>h</u>. Engine model:

   (1) Horsepower

   (2) Number of cylinders

   (3) Fuel type

   (4) Type of cooling

Background noise

4-11. In a given area, magnetic perturbations can be found that determine the magnetic background noise for each given area. Magnetic background noise is generally classified as (a) geologic, where magnetic anomalies, such as ore deposits, produce large gradients over a localized area; (b) geomagnetic micropulsations or variations in the earth's magnetic field with time, which may be of extraterrestrial origin and spatially coherent over large areas or produced by local effects, such as lightning storms; or (c) cultural contamination or noise generated by close proximity to power lines or near ferromagnetic objects, such as shell cases, parts of vehicles, etc. Noise (b) is most frequently the source of sensor false alarms. The magnetic background noise level and descriptive locations of known components should be accurately documented. As a minimum, the ambient magnetic field should be measured at several locations on the test site, so that the magnetometers (see paragraphs 4 18 through 4-21 for discussion of magnetometers) can be placed in an area free of local magnetic anomalies. In general, the test site should be chosen so as to be as far away as possible from power lines, reinforced concrete highways, pipelines, and other ferromagnetic items, since these materials can affect magnetic signatures at distances from less than 5 to more than 1000 m. If the signatures must be obtained in a noisy environment, the source of magnetic background noise should be described as precisely as possible, including (but not limited to) the following:

  <u>a</u>. Name of source (pipeline, highway, iron ore)

<u>b</u>. Continuous or transient

<u>c</u>. Distance from source

<u>d</u>. Attitude from source

<u>e</u>. Velocity of the source and direction of motion, if appropriate

Documentation of Test Site Conditions

4-12. Test site conditions have considerable impact on the nature of the magnetic signals from a target. In general, the test sites should be prepared in a specified manner for the particular tests to be conducted. The test layout must be studied on the ground to determine the location of sampling points for the terrain factors that affect the propagation of the magnetic energy. The location of the test course layout and terrain factor sampling points should be determined with sufficient accuracy to permit their relocation at any reasonable time in the future. The best available aerial photographs and topographic and geologic and geomagnetic survey maps (U. S. Naval Oceanographic Office) should be obtained before a visit to a prospective site. At the site, the sampling point (or test course layout) should be located on the maps and/or aerial photographs as accurately as possible. A detailed sketch of the immediate vicinity should then be made to permit reloca- tion of the sampling points. The location of the site should be speci- fied by the geographic coordinate system (degrees, minutes, and seconds of latitude and longitude) or by the Military Grid Reference System. Details of both systems can be found in Reference 4-2.

4-13. Surface terrain factors, surface soil data, vegetation data, and other data, such as geologic, physiographic, and meteorological, are needed in the interpretation of the signature data recorded. Specific additional requirements are discussed in the following paragraphs.

Surface terrain factors

4-14. The geometry and rigidity of the surface over which a target travels cause fluctuations in the magnetic signature of the target. Major surface irregularities may change the orientation of the magnetic

moment of the target; therefore, these irregularities should be documented.

4-15. Surface microgeometry profiles should be measured with a good-quality surveying level or theodolite. Rod readings accurate to at least 1 cm should be made at all major breaks in the target paths (see paragraph 4-29) to define the irregularities. In addition, photographs of the ground surface should always be obtained. To ensure that the relative elevation of the sensor and target is documented, the surface geometry between the target and magnetic sensor should be defined. In general, sufficient topographic data should be taken to construct contour maps of the area between the target and magnetic sensor with a contour interval of 50 cm.

Surface soil data

4-16. Natural anomalies caused by iron-bearing minerals in the soil may range from less than one thousandth to one tenth of the earth's magnetic field. For this reason, the presence (and amounts) of these minerals should be determined by laboratory analysis of surface soil samples obtained from the test site. The largest natural anomalies normally result from the presence of magnetite; however, significant anomalies can result from hematite, glauconite, hornblende, limonite, etc. In addition to the information on the presence of iron-bearing minerals, data on soil moisture and soil type should be collected for each test site. The soil of each site should be classified according to the Unified Soil Classification System.[4-3]

Supplemental site descriptive data

4-17. Geologic, physiographic, and meteorological data on the site can be quite useful in interpreting and extrapolating the test results from the site to other areas. Normally, these descriptions will have to be prepared with the aid of personnel (Soil Conservation Service staff, etc.) familiar with the area. The information should include a statement on geology, names of the physiographic and landform units, site topographic position, depth to the water table, land use, soil parent material, and description of the soil profile.[4-4] The land use should be listed in terms such as undisturbed, logged, grazed,

cultivated (idle), cultivated (grazed), bare, etc. Further, wind velocity and direction, temperature, and precipitation (i.e. rainfall and/or snowfall) should be recorded during the test period. Often, it may be desirable (from an economic standpoint) to obtain weather station records in lieu of on-site measurements. The location of the nearest and most representative weather stations should be identified to determine whether their records would be representative of site conditions. Geomagnetic survey maps should be obtained for the test site. These maps are available from the U. S. Naval Oceanographic Office, Washington, D. C., for most areas. A quick magnetic survey of the test site may be desirable to identify local variations. The survey can be made by taking several measurements in the area with a standard d-c magnetometer having 1-microtesla sensitivity.

Instrumentation for Recording Magnetic Signals

Magnetic sensors

4-18. The equipment needed for typical a-c and d-c sensor systems used to measure signatures of a ferromagnetic target traversing the earth's geomagnetic field is listed below, as an example of the types of sensors and supporting equipment available. This equipment has been used recently in signature acquisition programs conducted by the U. S. Army Tank-Automotive Command (TACOM) and the U. S. Army Mobility Equipment Research and Development Center (MERDC).

4-19. The d-c magnetic equipment used by TACOM[4-5] is as follows:

   a. <u>Triaxial Fluxgate magnetometer.</u> 3-channel Automation Forester Model MF-55-331, consisting of three Model MF-5050 units mounted in a single housing.

     (1) Location: 0 to 15 m from closest point of approach, measured perpendicular to the target path. Signal output is extremely sensitive to transducer-to-target distance

     (2) Range: 0.1 to 1000 millioersted (80 db) through gain switching

     (3) Resolution: 1×10^{-3} millioersted

     (4) Accuracy: ±1 percent of full scale of selected range

(5) Output: 1 v (1000 ohms input impedance)

(6) Frequency response: DC to 300 Hz

b. 60-Hz notch filter. Burr-Brown (BB) Model 5158-BRIP-60RO. This is a special-purpose filter with electrical specifications similar to BB 5717-BRIP-60RO (one for each channel). The three outputs of the magnetometer pass through these notch filters before being recorded on magnetic tape.

(1) Center frequency: 60 Hz, adjustable by ± 0.1 Hz

(2) Q: 10 ± 10 percent

(3) Passband gain: 0 ± 0.2 db

(4) Rejection in notch: 40-db minimum

(5) The d-c offset: ± 2 mv

c. High-pass filter. BB Model 5713-HP7B-5R00/16. In addition to passing through a notch filter, the vertical output of the magnetometer is routed through this high-pass filter.

(1) Cutoff frequency: 5 Hz (-3 db point)

(2) Type of filter: 7-pole Butterworth

(3) Passband gain: 0 ± 0.1 db

(4) The d-c offset: ± 5 mv

4-20. The a-c magnetic equipment used by TACOM is as follows:

a. Antenna, loop. Fairchild Model ALP 10

(1) Size: 63.5-cm diam

(2) Sensitivity and frequency response: The response of the loop is proportional to frequency

(3) Location: 0 to 5 m from closest point of approach, measured perpendicular to target path. Signal output is a function of target distance

(4) Elevation: Center of loop 35.5 cm above the surface of test lane

b. Amplifier, decade. Industrial Instrument Model 40-A1

(1) Gain ranges: 1, 10, 100 $\pm$ 1.0 db. The amplifier gain is controlled by a vernier, which is set to produce a gain of 3.7 on the ×10-range setting and a gain of 37 on the ×100-range setting

(2) Frequency response: 3 to 100,000 Hz $\pm$ 10 percent at the 100,000-Hz setting

(3) Noise: 105 µv for ×1-gain; 20 µv for ×10-gain;

7 μv for ×100-gain (broadband rms values referred to shorter input)

    (4) Distortion: 0.2 percent at 0.2-v rms output; 1 percent at 0.5-v rms output

  <u>c</u>. <u>Interference analyzer</u>. Fairchild Model EMC-10

    (1) Frequency response: 20 to 500,000 Hz

    (2) Voltage accuracy: $\pm$0.^{r} $_1$o, 20 to 50,000 Hz

    (3) Output: 1-v rms for meter at full scale

4-21. The a-c magnetic sensor used by MERDC is a T-4 coil transducer combined with a signal conditioner supplied by MERDC. Two outputs are available—high-frequency band and low-frequency band.

  <u>a</u>. <u>Frequency response</u>.

    (1) High-frequency output: 10 to 300 Hz, 3-db passband; 7.5 to 370 Hz, 6-db passband

    (2) Low-frequency output: 0.1 to 2.0 Hz, 3-db passband; 0.05 to 3.5 Hz, 6-db passband

  <u>b</u>. <u>Location</u>. Determined by type of test lane

  <u>c</u>. <u>Elevation</u>. 50 cm above the surface of the test course. The coil is packed in a Styrofoam container with polyurethane and placed on a mound of fine gravel adjacent to the test lane

  <u>d</u>. <u>Signal conditioning</u>. Philbrick RP manifold with EP85AU differential operational amplifiers. Offset voltages from the magnetometer are compensated for with a stable voltage source and these amplifiers. Signal gains are determined by adjusting amplifier feedback and input resistances

4-22. In addition to the equipment listed above, it should be noted that a well-equipped magnetic acquisition facility (i.e. the Harry Diamond Laboratory facility) is located at Aberdeen Proving Ground, Maryland. Since this facility is permanent, vehicles must be transported to it for testing. There are numerous manufacturers of magnetic sensing devices, including Develco, Inc., Mountain View, California; Schonstedt Instrument Company, Reston, Virginia; Infinetics, Inc., Wilmington, Delaware; and Electro-Mechanics, Inc., Austin, Texas.

<u>Recording circuits</u>

4-23. An analog signal recording system records each magnetic

signal on a separate channel (track) on magnetic (data) tape. In addition, a time-code signal (accurate to 1 msec), a time-event signal (a simple keyable voltage), and a voice-identification signal are also recorded on separate tracks. The time-code signal serves as a precise time reference so that even if the tape speed and reproducing systems are not within tolerances, the time between events and spectral content can still be recovered. The time-event signal serves as a convenient way to record the instant a target position has been referenced (i.e. passed a location stake; see paragraph 4-29). The position of the target and other pertinent test information can be identified on the voice track. Support equipment for the recording system normally includes a voltmeter and oscilloscopes to measure pertinent voltage amplitudes and wave forms in the system or for normal troubleshooting procedures.

4-24. The test data are recorded on a high-quality magnetic tape recorder with both FM and direct-record electronics. The tape speed is determined by the expected target signature and type of data analysis. Speeds of up to 38.1 cm/sec are usually sufficient. The measured signals should be monitored during actual recording with a multichannel strip chart recorder, if possible, to ensure that "good" data recordings are obtained. It is highly desirable to detect and correct any problems at the time of actual recording. Quality of data is far more important than quantity, and every effort should be made to improve quality.

4-25. Schematics of the equipment used in recording the magnetic signatures should be prepared carefully. The field data log should contain the following information with regard to the equipment and the signals recorded:

     a. Tape width, length, reel size

     b. Total number of channels

     c. Recording mode (FM, direct, PCM, etc.)

     d. Tape speed (in./sec)

     e. Recording density (per Inter-Range Instrumentation Group (IRIG) standards, i.e. intermediate, wide-band I, or wide-band II)

<u>f</u>. Frequency response (direct, FM)

<u>g</u>. Other pertinent information: center frequency, percent
deviation, reference IRIG time code, footage readings,
revolution counter, voice edge track (A or B), sync
reference signal, tape thickness

Calibration

4-26. An important part of any magnetic data collection program is
the calibration of all components of the system. The calibration equip-
ment should have performance specifications that exceed those of the
complete recording system, and all equipment (including the sensor and
recording system) should be documented as to manufacturer, type, modi-
fications, and operating conditions. Calibration signals should be
recorded at the beginning of each test sequence. The calibration should
be introduced to the recording circuit at the amplifier. The magnetom-
eter signal should be replaced with a precise voltage proportional to
the sensitivity of the magnetometer. Whenever any electronic equip-
ment affecting calibration has to be replaced or adjusted, the cali-
bration must be repeated. It is desirable to use a calibrated magnetic
dipole permanent magnet as a standard to obtain signatures for precisely
known distances. For example, an AK-47 rifle typically is equivalent to
a 500-CGS dipole moment, and a permanent magnet can be used for simu-
lation and to check for proper system operation/calibration. Use of a
calibrated solenoid cable for producing known fields at the sensor is
also desirable in checking system calibration.

4-27. Magnetic units commonly used are the CGS system, in which
a field from a dipole may be approximated by $H = m/r^3$, where H is in
oersteds (1 oersted = 10^5 gamma = 10^5 nanotesla), and r is the closest
point of approach in centimeters. A 2-1/2-ton truck has a typical moment
of 5×10^5 CGS units, and approximate component fields can be determined
for the purpose of scaling. The magnetic moment is determined by the
amount (i.e. weight) of ferromagnetic material present in the target.

Test Procedures

Selection and preparation of test site

4-28. The selection of each test site will be determined by the

target being tested and the sensor capabilities. In general, the test course should be relatively level and have a surface firm enough to prevent excessive rutting under multiple passes of a vehicle. To provide information for multiple uses (e.g. mine- and intrusion-detector logic design), signatures should be obtained with magnetometers (a) buried approximately 7.5 cm, (b) lying on the ground surface, and (c) suspended 50 cm above the ground surface.

4-29. Test lanes should be laid out as shown in Figure 4-1.
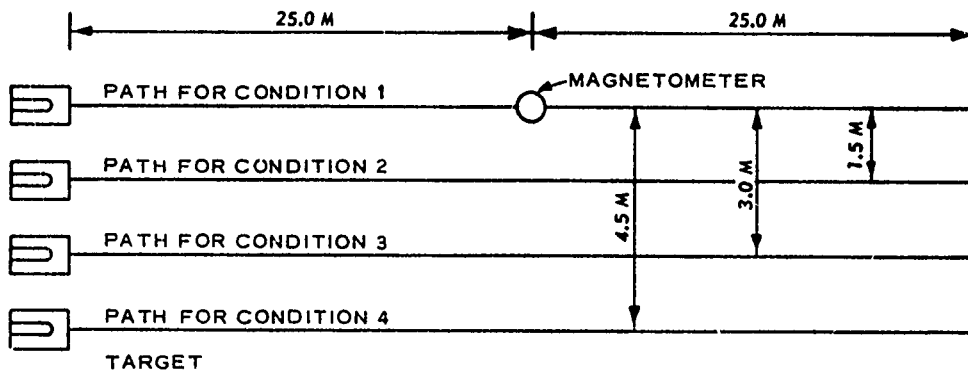
Figure 4-1. Location of target path and magnetometer for signature acquisition

The vehicle should make identical passes in the north-south, south-north, east-west, and west-east directions. (If the magnetometer is suspended, condition 1 in Figure 4-1 must be omitted.) The length of the test lane will be determined by the target; but for most military targets (e.g. a tank), a test lane of 50 m will be sufficient. Stakes should be spaced at 1-m intervals with the zero stake at the center of the test lane. Accurate documentation of sensor emplacement should be stressed to the data collection team, because the quality of the data recorded can be no better than the ability to locate the target with respect to the sensor.

Operational parameters

4-30. Static or idling tests. Each target will present discrete magnetic moments; therefore, static signatures of each target should be

recorded at the closest point of approach (CPA) and at two detection
extremes (DE) of the test lane (condition 1 in Figure 4-2). A single
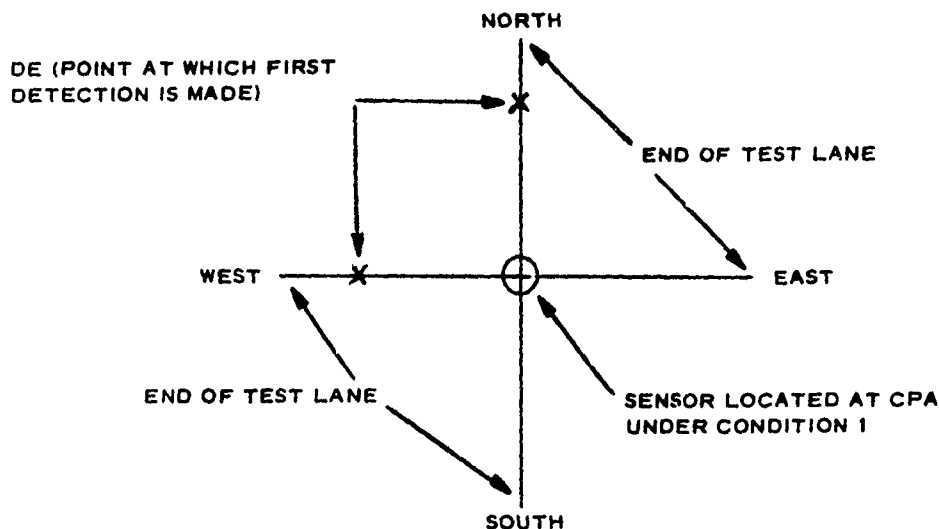

Figure 4-2. Static test layout

test should consist of the target placed in a specified orientation
(e.g. facing north) with the engine (if a vehicle) running at an rpm
equivalent to that required to propel the vehicle at 32 km/hr. At least
a 1-min recording should be made. This basic test should be repeated
with the vehicle facing north, south, east, and west at one DE for the
north-south direction, one for the east-west direction, and one for the
CPA. Thus, each test site will be characterized by 12 static signature
tests. Because configurations of military targets, i.e. fully equipped
combat soldier, aircraft, wheeled and tracked vehicles, etc., vary,
signature data must be completely documented as to target direction,
height, length, etc.

4-31. Dynamic tests. Dynamic tests should be conducted with each
target operating at specified speeds. These speeds should be repre-
sentative of those expected in tactical field operations. For example,
wheeled and tracked vehicles should be operated at 7.5, 20, and 32 km/hr,
whereas a normal pace would be suitable for the walking-man target. The
time the target passes each stake (1-m interval) should be determined
and recorded on the voice channel of the recorder. Also, the velocity
of the target should be recorded for each pass. The target should

4-13

travel at a constant speed along the entire test lane. At least 10 sec of background noise should be recorded at the beginning of each test run. It is emphasized that complete documentation of the test scenario is required. Voice documentation should be used to make a complete history of the test. Ambient noise levels of naturally occurring phenomena, such as rain, high winds, thunder and magnetic storms, etc., should be recorded for 10-min intervals during major periods of the 24 hr preceding the test. Meteorological data should be recorded for the duration of the test period if at all possible. These data should consist of wind speed and direction, air temperature, barometric pressure, relative humidity, and direction and distance of lightning.

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Transfer of Energy from the Seismic Source to the Substrate

1. The generation, propagation, and sensing of seismic energy
from targets of military interest consist of a sequence of interrelated
physical phenomena (Figure A1). The sequence starts with the target.

2. Anything that moves on the surface of the ground applies a
force to the substrate. The thing may be a man, a vehicle, the pressure
pulse of an acoustic wave, an animal, or even trees being moved slightly
by the wind. If the force is raised to a level such that the substrate
is stressed enough to deform, even if only minutely, the energy is car-
ried away from the point of deformation by seismic waves. The implica-
tions of the statement that anything that applies a force to the sub-
strate of sufficient magnitude to stress and deform it will produce a
seismic wave train should be thoroughly understood. For example, wind
blowing through trees and shrubs transmits forces down the stems and
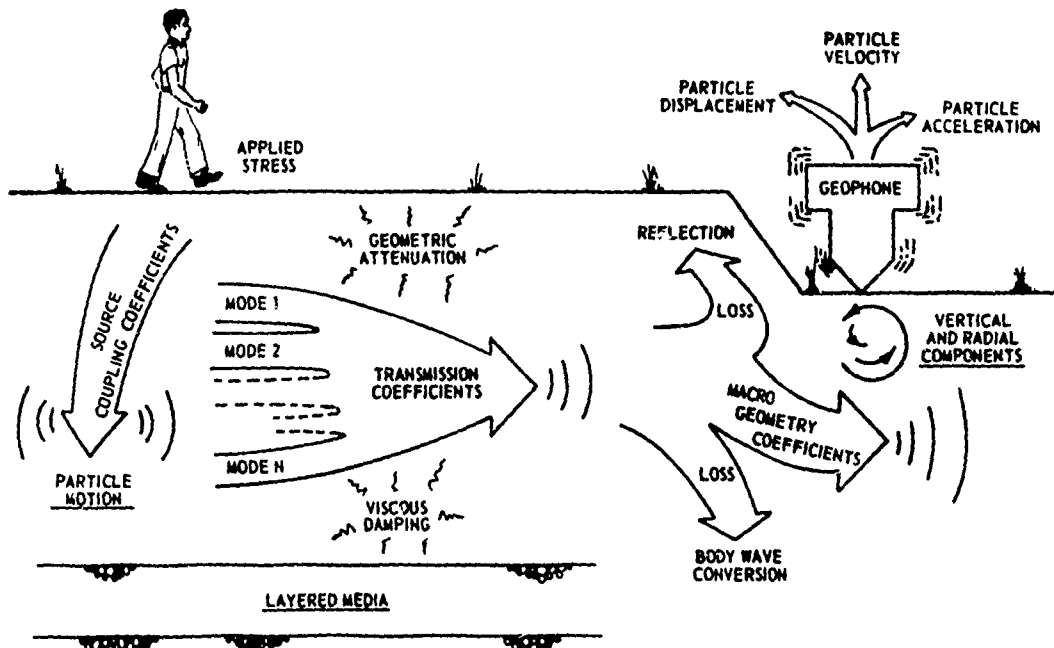
Figure A1. Signal generation and propagation of microseismic waves

into the substrate, and the deformations result in the generation of seismic wave trains. Those waves are not qualitatively different from the ones produced by a moving tank. A passing train produces seismic signals; so does traffic on highways. Factories produce seismic signals. In fact, the active crust of the earth produces seismic wave trains throughout the surface of the globe. No area on the planet is entirely free of such extraneous wave trains, and those waves will inevitably be sensed by the geophones used in seismic signature acquisition just as will the waves from a military target. The point is that if one is interested in detecting a specific type of target, "false alarms" will always occur; the only point of issue is their frequency.

3. The amplitude and, to some degree, the type of seismic wave generated depend upon its stress history. For example, a walking man applies a localized force at the point of each footfall, and that force and the resultant substrate stress are characterized by a particular relation between magnitude and time. That is, the force is not applied instantaneously; rather, it rises and falls according to a particular pattern, even though the entire time involved is only a fraction of a second. This "force-time history" can vary remarkably. The major variations can be classed as (a) variations in the nature of the target itself, and (b) variations in the nature of the substrate (soil, rock, pavement, snow, or any other material composing the medium on which the target is moving).

4. Variations in the nature of the target are important because they result in differing rates and magnitudes of force application to the substrate. That is, they affect the force-time history by which the available energy is applied to the substrate. The major potential variations are size of the mass and rate of force application.

5. Other things being equal, a large mass will result in greater forces than a small mass, and these will, of course, be reflected in the force-time history. Thus, a large man tends to produce a force-time history different from that of a small man; this also is true for large and small vehicles.

6. Again, other things being equal, a force applied rapidly will

produce a force-time history different from that of the same force applied slowly. Thus, a man placing his feet slowly and carefully on the ground will produce a force-time history significantly different from that produced by the same man walking normally. Similar differences occur in the force-time histories of vehicles. For example, a wheeled vehicle moving on a smooth, even surface applies force relatively smoothly, without sharp discontinuities in force level. On the other hand, the track pads of a tracked vehicle strike the ground sequentially and thus produce a force-time history consisting of a series of high- and low-force levels. Obviously, the rate at which those cycles occur is a function of vehicle speed. This situation becomes even more complex if the surface over which the vehicle is moving is irregular, since in this instance, the dynamic response of the vehicle, regardless of whether it is wheeled or tracked, will result in maxima and minima in the forces applied to the substrate.

7. Variations in the nature of the substrate may also affect the force-time history, since that history is a record of the relation between force and time as measured at a specific point. If the surface is soft and spongy, the thing applying the force (i.e. an infantryman's foot, the track pad of a tank, etc.) requires a longer time between initial contact and achievement of maximum force level than would be the case on a firm, hard surface. Thus, the force-time histories of the two situations will not be identical, even though no intrinsic changes in the character of the target are present. One implication of this is that the force-time history of a man walking in a sod-covered area will be different from that of the same man walking at the same pace in an area of bare ground.

8. The force applied to the ground surface creates a set of stresses in the substrate material, and if the stress level is high enough, measurable deformation occurs. The energy of deformation is then carried away from the point of deformation by seismic waves. Thus, it follows that the stress-time history and the characteristics of the substrate materials control the nature and magnitude of the seismic waves.

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Propagation of Seismic Energy

9. There are three major seismic wave modes, all of which move radially outward from a point of substrate deformation (i.e. the point at which stress is applied): (a) compression waves (P-waves), in which the principal particle motion is along a radial; (b) shear waves (S-waves), in which the principal particle motion is at right angles to a radial; and (c) surface waves (Rayleigh waves), in which the principal particle motion is elliptically retrograde in a plane chiefly perpendicular to the surface of the propagating medium. Compression waves move in all directions, so that the advancing wave front is approximately a hemisphere. However, they do not necessarily move at the same velocity as the S-wave even in the same material. Unlike P-waves and S-waves, Rayleigh waves move only at shallow depths and parallel to the surface, so that at a point a few meters from the target, the advancing wave front is cylindrical with the vertical axis of the cylinder at the target. For all practical purposes, Rayleigh waves (assuming very low amplitudes that are of interest in seismic intrusion detector (SID) utilization and design) affect a substrate depth equal to about one-half wavelength. Amplitudes of Rayleigh waves are at a maximum at the surface and decrease progressively with depth. The propagation velocities are not the same as those of either P-waves or S-waves.

10. Generally, both P-waves and S-waves are diffracted in the direction of greater substrate densities, and since nearly all natural substrates increase in density with depth, these waves tend to diffract downward. The result is that they appear to attenuate very rapidly at the surface. They may, however, reflect from a subsurface discontinuity and reappear at the surface at some distance from the target. Thus, there may be zones in which P-waves and S-waves cannot be detected at the surface. Conversely, the Rayleigh wave propagates only along the surface; thus, there can be no discontinuities in the area over which the signal can be detected. This knowledge, in addition to the fact that about two-thirds of the energy at the source is carried away in the Rayleigh wave, is the principal reason for choosing the Rayleigh wave

as the mode upon which to base SID designs.

11. All seismic waves are affected by the nature of the materials through which they propagate. However, since the Rayleigh wave is the principal mode of interest, the following discussion will be restricted to matters of concern to Rayleigh wave propagation.

12. The "ideal" situation for the propagation of Rayleigh waves would consist of a completely homogeneous elastic half-space. Anything that departs from these ideal conditions serves to attenuate or disperse the wave form more rapidly than would be the case by purely geometric attenuation (i.e., the attenuation resulting from the same amount of energy being applied over a longer wave front as the wave moves outward away from the source). There are several basic types of nonhomogeneities commonly found in nature. The dramatic effects of nonhomogeneities on wave propagation stem primarily from the fact that each type of material tends to act as a specific medium for a specific suite of wave frequencies. That is, a specific type of material tends to propagate certain frequencies more efficiently than others. The result is that substrate materials act as selective filters. For example, most targets generate a seismic wave train (or signal) consisting of a complex of frequencies (or wavelengths) ranging from very low (i.e. very long waves) to very high (i.e. very short waves). Generally, the signal contains a broad spectrum of frequencies as it emerges from the source. However, as the wave train moves radially away from the source, two things happen to it:

a. Since each frequency tends to propagate at a slightly different speed, the wave train tends to separate into sections (disperse), each having a characteristic frequency. This effect is usually not obvious over short distances, since the process rarely has time to produce complete frequency separation.

b. Some frequencies are propagated efficiently over rather long distances, and others die out quickly. The effect of this phenomenon is to filter out some of the original frequencies, leaving a signal characterized only by those frequencies that are efficiently propagated. In practical terms, the implication is that in some terrains and at long detection distances all targets tend to be characterized by wave trains exhibiting the same

A5

frequencies. It is obvious that, in such situations, virtually all targets will look the same insofar as the frequency composition of their signatures is concerned.

13. There are several basic types of variations in substrate characteristics, each of which interacts with the seismic wave trains in specific ways. One such basic type is stratification. Nearly all substrates are stratified to some degree, and many are divided very sharply into distinct layers. For example, most agricultural areas are characterized by soils having a minimum of three more or less distinct strata: (a) a disturbed layer, down to plow depth, consisting of relatively low-density materials; (b) a layer in which the parent material is only partially modified by soil-forming processes; and (c) a layer consisting of the original parent material, which is often rock. Each such layer tends to be characterized by somewhat different propagation characteristics with the result that the seismic waves try to propagate independently through each. The interference that occurs at the interfaces absorbs energy, and the wave as a whole, therefore, tends to attenuate rapidly. Many other conditions of stratification also occur; the hand of man is not required to produce them.

14. It should be noted that stratification is not a constant with respect to time. The most common cause of a change in stratification is a change in moisture content. The presence of water in a soil affects the overall density, intraparticle adhesion, and in some cases even particle orientation, all of which change the elasticity and/or viscosity of the soil and, therefore, the wave propagation characteristics. The effects of moisture are often dramatic. For example, the deep, nearly homogeneous, silty sand soils that occur along the Gulf Coast of the United States seem superficially to approach the ideal as a propagation medium and do indeed approach the ideal during periods when moisture content is uniform throughout the soil mass. However, during and for a short period after rain, the near-surface soil stratum is near saturation, whereas the soil at depth has a much lower amount of contained water. The consequence is an effective, if temporary, stratification that may result in a more rapid attenuation of the

seismic wave than would normally be the case. In practical terms, this means that the seismic energy emanating from a target might be significantly reduced during the period of stratification. Somewhat similar situations can occur and persist for longer periods; for example, detection distances in some tropical situations are characteristically less during the wet season than during the dry.

15. A change in stratification of the kind described above may also result in a change in the frequency characteristics of the signal as a function of time. The reason is that a wet soil may not efficiently propagate the same frequencies as the same soil in a dry state. The practical effect of this phenomenon (see paragraph 12) is that the signals arriving from the same target at the same distance may be different in wet and dry seasons.

16. A second basic type of variation in substrate characteristics is facies changes. Nearly all substrates change laterally to some extent, and in many geographic situations such changes occur abruptly and within short distances. This phenomenon may have important effects on seismic wave propagation if an interface occurs between the target and the geophone. For example, consider a situation in which the first half of the propagation medium consists of a material that efficiently propagates low-frequency waves but quickly attenuates high-frequency waves, and the second half consists of a material that efficiently transmits high-frequency waves but not low-frequency waves. The signal leaves the target with a normal spectral composition of both high and low frequencies. During the first half of the path, all of the high frequencies are attenuated and lost, so that only low frequencies remain as the signal crosses the interface between material types. Since the second type will efficiently transmit only high frequencies, the low frequencies will be quickly attenuated and lost, leaving nothing. The practical implication of these observations is that a seismic wave train may be eliminated in a distance less than would be the case if the entire propagation path were in either one of the substrate types.

17. Nonhomogeneities in the soil mass are a third basic type of variation in substrate characteristics. Many substrate materials

consist of particles that are both small with respect to the size
(i.e. wavelength) of the seismic waves that propagate through the sub-
strate as well as particles that are roughly equal to the size of the
propagating wave. On the other hand, many soils consist of aggregates
of different materials, some of which contain relatively large-size
particles, such as boulders in sand. The effect is somewhat like plums
in a pudding. In addition to the size disparity, there are many situa-
tions in which the "plums" exhibit elastic and/or viscous properties
markedly different from those of the matrix material.

18. Such internal nonhomogeneities may arise from a number of
causes. For example, the widespread boulder-clays of the northeastern
United States are materials in which the matrix is basically silty
clay, and the plums are cobbles and boulders of solid rock. In forested
areas, the nonhomogeneity may be caused by the roots of trees. In arid
and subarid climates, discontinuous masses of caliche (a form of calcium
carbonate) may form in the soil. In the Arctic, the plums may be ice
wedges buried in the soil.

19. Generally, substrate materials exhibiting this type of nonhomo-
geneity attenuate all seismic waves much more rapidly than a homogeneous
material of comparable elastic and viscous properties. However, the
effect is usually more dramatic on high frequencies than on low. The
reasons are to be found in the frequency-dependence of propagation
efficiencies (paragraph 14). For example, consider a material such as
a fine sand with large rocks in which the matrix efficiently propagates
low frequencies. A broad-spectrum signal propagating through such a
material will be rapidly attenuated because of a complex of phenomena:
The high-frequency components are quickly filtered out because of the
properties of the matrix, the low frequencies are attenuated because
the basic wave forms are distorted as they pass around the plums.

20. Yet another basic type of variation occurs as changes in
surface geometry. Very few terrains exhibit perfectly planar surfaces,
the ideal situation for the propagation of Rayleigh waves. Instead,
nearly all are irregular to some degree. Generally, the more irregular
the topographic surface the less efficient is the propagation of the

Rayleigh wave. There is, however, one important proviso; namely, that the irregularities be large enough to interfere significantly with the wave form, but not so large that one or more wave forms can be accommodated on the feature. Since the wavelengths that are of primary interest from the point of view of SID design and utilization vary in length from about 2 to 50 m, it is obvious that surface-geometry feature size is also frequency-dependent. That is, a feature (such as a ditch) that is 1 m across may well interfere significantly with the propagation of a high-frequency wave (i.e. a wave having a length of only a few meters), whereas it might not interfere significantly with a low-frequency wave (i.e. a wave having a length of tens of meters). The converse is also possible; that is, a high-frequency wave may not be significantly affected by a feature tens of meters across because several complete wave forms of the high-frequency wave can be accommodated on it.

Transfer of Seismic Energy from the Substrate to the Geophone

21. The previous paragraphs have dealt with the transfer of energy from a seismic source to the substrate and the propagation of seismic waves within the substrate. The following paragraphs present a brief discussion of the phenomena dealing with the transfer of seismic energy from the vibrating medium (i.e. substrate) to the geophone.

22. As the propagating seismic wave passes the geophone, it is carried along by the motion of the substrate particles if the geophone is properly placed in contact with the ground. There are three major conditions that can affect geophone performance: (a) depth of emplacement, (b) geophone attitude, and (c) coupling of the geophone with the substrate material.

23. In the context of geophone emplacement depth, it must be recalled that the particle motion produced by a Rayleigh wave is at a maximum at the surface, and that the amplitude decreases as a function of the ratio depth/wavelength of the substrate material and becomes effectively undetectable at a ratio of 1:2 in almost all substrate materials. The practical effect of this characteristic of the wave

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mode is that the maximum signal is sensed when the geophone is at or very close to the surface. Thus, if a geophone is emplaced at a depth of 1 m, the amplitude of the particle motion at that depth will be somewhat lower. This effect becomes more and more pronounced with depth even in nonstratified substrates.

24. If the substrate is strongly stratified, the effect may be even more pronounced. This situation can occur if the second layer has propagation characteristics markedly different from those of the surface layer. In this situation, it is common to find that very little of the available energy is coupled into the second layer; therefore, the particle motion is very small. Thus, a geophone emplaced in the second layer may be scarcely affected by a wave passing above it, i.e. being propagated almost entirely in the surface layer.

25. From these considerations, it is evident that depth of em-placement of the geophone is critical. If it is placed too deep, the geophone may be below the zone in which active particle motion is taking place.

26. Nearly all geophones operate at maximum efficiency when the axis of the geophone is parallel to the pull of gravity. The point is that the geophone should be vertical with respect to sea surface, not vertical with respect to the substrate surface (except when sea level surface and the substrate surfaces are parallel). The geophones become less efficient with increasing angles of inclination, and most become completely inoperative at angles from the vertical of between 45 and 60 deg, depending upon type.

27. For the particle motion produced by the wave to be sensed by the geophone, the case of the geophone must move as if it were a sub-strate particle. Generally, this condition can be achieved only if the geophone is in intimate and solid contact with the substrate. If it is not, only a fraction of the real particle motion may be transferred to the geophone, with the result that the geophone will record the passing of a wave having an apparent amplitude of much less than that of the real wave. The practical effect of this phenomenon again is a reduction in the signal sensed by the geophone.

28. Finally, failure to achieve adequate coupling between the ground and the geophone will result in an erroneous measured signal. Good coupling can be assured by proper emplacement of the geophone as described in paragraph 2-31, Part 2, of the main text.

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